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PROSPECTS FOR DAIRY FARMING

One of the outstanding features in British agriculture during the past ten years has been a rapid increase in milk production to the point where the seasonal supply can sometimes be an embarrassment. This was evident in spring 1957, when, stimulated by an abundance of grass, the output broke all records and created a temporary surplus. A situation is now developing that will affect the whole economy of the dairy farmer, and we briefly review the changes that have brought it about and indicate its practical implications.

Several of the fundamental changes were initiated during the last war, when every effort was made to provide as much milk as possible for consumption in liquid form. To achieve this end, and to allow for some decline in the average yield under wartime conditions, the national herd was steadily expanded and dairy farming was extended into new areas. The amount of milk fed to young stock and used for butter and cheese making was reduced to a minimum, and calving dates were altered to ensure a more uniform supply of milk throughout the year. While this was in progress imports of feedingstuffs were drastically cut and more than one-third of the permanent pasture was converted into arable land and leys, compelling farmers—many of them new to dairying—to support their cattle on homegrown food, especially grass, grazed and conserved. By such measures the supply of liquid milk was well maintained, and the war ended with the dairy industry established on a new footing. Developments which seemed at that time to be temporary expedients have since become standard practice, and various other advances coupled with a substantial increase in cow numbers have provided enough liquid milk to raise the consumption per head of the population from a weekly 3 pints pre-war to 4·9 pints last season—more even than that in the U.S.A.

The technical achievement is manifest in the rise in the average yield per cow from 560 gallons in 1938–9 to 680 gallons in 1955–6. Better feeding and management are said to be responsible for much of this gain, and it is significant that 20% more dairy cows as well as other animals are now being maintained on a far smaller area under grass using less imported concentrates than before the war. About one-quarter of the increase is attributed by the Milk Marketing Board to a change of breed from dual-purpose to dairy types, which at present constitute two-thirds of the national herd compared with about one-half in 1950 and a mere one-seventh before the war. Improved breeding has also been an important factor, but it is doubtful if artificial insemination, which became widely adopted from 1944 on, has had much effect on yields. To what extent improved animal health has contributed to the rise no one in authority will venture an opinion; on a rough estimate, however, effective control of the major diseases probably accounts for at least one-quarter of the overall gain in the yield per cow. To this may be added any increase due to a higher rate of culling of low-yielding animals.

From the administrative viewpoint the chief problem now is to avoid overproduction. Even if the national herd is kept about its present size yields per cow will continue to rise, and because the extra milk will amount to more than the liquid market can absorb, allowing for increase in the population and a reasonable improvement in consumption per head, the surplus must be diverted to the manufacturing market. Movement in this direction has already begun and can take up any excess likely to be produced in the near future without unduly affecting the interests of countries which at present supply the U.K. with 80% of its total requirements of dairy products.

Dairy farmers are inclined to see in this a risk to their prosperity, because milk prices are falling while costs of production are rising, and a higher proportion of milk going on the manufacturing market, where it may fetch as little as half the price realized by milk for direct consumption, will lower their profits still further. How this situation should be met is a matter for the individual to decide according to his system of farming and resources, but the general answer is to be found in greater efficiency and economy in production. Above all else full use must be made of the resources of grassland by good management directed to get plenty of rich young grass which, with controlled grazing and conservation of high-quality silage, can be used to reduce the mounting bill for purchased feedingstuffs and to lower the cost of milk production throughout the year. A government committee has recently been formed to investigate this problem in all its aspects. Other possibilities are to intensify production and to add some other enterprise to the farm, and there is ample scope for economy in labour by increased mechanization and its more efficient use in the shippon. The methods are known, and the dairy farmer who applies them can certainly look to the future with an easier mind than he who does not.

NEW DEVELOPMENTS IN REARING PIGS

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Great interest is now being taken by pig-keepers in the new rearing methods discussed in this paper. These show that piglets can be successfully weaned when a few days old and reared on milk substitutes. In this way more than two litters can be raised in a year and some of the losses met in natural rearing can be avoided; but substitute foods are costly, and much remains to be learned before the methods can be generally recommended.

The orthodox method of rearing pigs is to allow the dam to suckle her young for eight weeks. This method has now been practised for a very long time, and it is as well to remember all the important facts known about it before considering other methods of rearing which are currently being developed.

NATURAL REARING

A normal sow can give birth to more than two dozen piglets at one farrowing. An average of 12 pigs born and 8 reared up to 8 weeks of age is considered good. The average gestation period is 114 days, the normal lactation is 56 days, and it takes usually up to 7 days to get the sow in pig following the weaning of her litter. Altogether, therefore, the cycle occupies an average of 177 days. This allows for two litters to be produced comfortably during a full year.

The average loss of pigs during rearing is at present around 25% of the pigs born, of which more than half are lost during the first three days after birth. One of the major causes responsible for these early losses is the crushing of the piglets by the sow. Although some factors predispose the piglet to be crushed, such as weakness at birth, chilling and lack of food, the clumsiness of the sow and the disproportion of her size to the size of her piglets are usually the primary causes of overlaying. In recent years, provision of farrowing rails, farrowing crates and infra-red lamps has substantially reduced the losses from crushing, but even in piggeries with "all modern conveniences" the average losses of piglets during the suckling period are seldom less than 10%.

Normal Lactation

The standard method of rearing on the sow is based on an 8 weeks lactation. When and how this length of lactation was fixed is not quite clear, but presumably it originated from an endeavour to improve on the one litter per year of the wild animal and raise the output to two litters.

We now know quite a lot about the lactation of the sow. Immediately after parturition colostrum is available to the newly born pigs. The average composition of a sow's colostrum and of its normal milk are shown in Table I. Within a few days after farrowing there is a gradual change in composition, and from about the 4th to 7th day normal sow's milk is available to the piglet. Piglets that have not sucked from their dams are very susceptible to disease; the newborn pig is devoid of antibodies but absorbs them within minutes of obtaining colostrum. The main value of the colostrum may indeed be said to lie in the fact that it provides antibodies against various infections to which the piglets are exposed. With the use of improved techniques for withdrawing samples of milk from the sow [4] reliable average data on the constituents can now be given (Table I).

A sow will normally produce 12–15 lb. of milk daily, or 65–80 gallons during an average lactation. Many factors are known to affect the yield, but one of the more important is the number of functioning mammary glands, which in turn depends on the number of piglets being suckled. The peak of milk flow is reached at the 3rd or 4th week and is followed by a gradual decline. It has been estimated that during the first part of lactation a normal pig sucking its mother will receive about 1·8 lb. (850 g.) of milk per day.

TABLE I

THE CONSTITUENTS OF SOWS' COLOSTRUM AND MILK [4]

Constituent	Colostrum (%)	Milk (%)
Total solids	25·8	19·9
Fat	4·4	8·3
Solids not fat . .	21·4	11·6
Protein	17·8	5·8
Lactose	3·5	4·8
Ash	0·6	0·9

The average birth-weight of the piglet is 2·5–3 lb. For the first fortnight or so the litter is entirely dependent on the mother's milk for food. The amount of milk the sow can provide is usually sufficient to support optimal growth during the first 2–3 weeks only. Thereafter the quantity of milk provided by the sow becomes the limiting factor controlling the rate of growth of the litter. Litters brought up on mother's milk alone will average about 25–30 lb. live weight at 8 weeks of age.

The insufficiency of the sow's milk supply, particularly during the later stage of lactation, is now generally recognized, and most rearers provide "creep feeds" to supplement the suckling. These creep feeds are usually given to the piglets when about a fortnight old, so that this supplementary source of nutrients is available to them by the time the peak of lactation is reached. The amount of creep feed consumed by the piglet varies greatly, depending on many factors, but it can safely be said that the provision of creep feed has raised the average for weaning weights at 8 weeks old to about 35–45 lb.

Disadvantages of Natural Rearing

In practice the advantages of "natural" rearing are apt to be offset by disadvantages, such as are set out below.

1. The impossibility of rearing on the sow piglets born in excess of the number of teats available for suckling.
2. Complete loss of litter if the mother dies during parturition.
3. Starvation of piglets if lactation is interrupted owing to illness of the sow.
4. Considerable losses of piglets during the first 48 hours after birth.
5. Malnutrition of piglets owing to insufficiency of sow's milk, particularly in the late stages of lactation.
6. "Runt" pigs are produced when udders do not function properly and thus impede the normal supply of milk.
7. Nutritional deficiency trouble in piglets if the sow's milk lacks some essential nutrient, e.g. iron.
8. The necessity for heavy feeding of sows during lactation, lasting 56 days, to provide sufficient nutrients for the production if milk.
9. Loss of live weight in the sow (60–100 lb.) during the suckling period.

By eliminating or shortening the lactation period most of the losses occasioned by (8) and (9) can be avoided.

REARING ON MILK SUBSTITUTES

The serious impact of these difficulties on the economics of pig rearing has led in recent years to a growing interest in the possibilities of "artificial" methods of rearing by the use of "milk substitute" foods. Although a few attempts to prepare such a milk were made before 1948, two reports published in that year, those of Johnson *et al.* [14] and Bustad *et al.* [5], stimulated much of the subsequent work on sow's milk substitutes. The main developments to date are summarized in the following points:

(*a*) At present no satisfactory substitute is known for colostrum. Under special laboratory conditions pigs can be reared without colostrum, but access to it is still considered essential in practice. This means that pigs intended for artificial rearing have to be left with the sow for the first 24–48 hours of their lives.

(*b*) Because piglets at birth, or soon after, will take only liquid nourishment, milk substitutes must be composed of readily soluble components. The liquid must be homogeneous, and neither sediment nor separation on the surface can be tolerated. Milk substitutes with the required physical properties can nowadays be prepared, but only by using rather costly purified ingredients. The problem, however, of attaining equally good results with the less expensive, commonly used feeding stuffs remains to be solved.

(*c*) Even the one-day-old piglet will feed from a shallow trough. There is no need to heat the liquid to body temperature before feeding, and milk substitute can be satisfactorily fed at room temperature or at ordinary refrigeration temperature. These findings should eliminate the use of gadgets either for heating the substitutes or for feeding the piglets through teats. They may also solve some of the problems connected with the keeping quality of milk substitutes and with the hygiene of the feeding routine.

(*d*) When about one week old, the piglets will take solid food in the form of either meal, crumbs, or pellets.

Artificial Rearing and Early Weaning

On the basis of these developments two new methods of rearing have recently come under trial, with promising results. These may be called "artificial rearing" and "early weaning," and are discussed as such in this and subsequent sections.

Artificial rearing may be regarded as taking pigs away from their mother when they are 1–2 days old, feeding them on liquid milk substitutes in strictly controlled environmental conditions, and gradually bringing them on to solid food so that by the 14th day they are completely on dry feeding.

Although this kind of rearing can be carried out satisfactorily under laboratory conditions there are still some difficulties to be surmounted before it can be adopted by pig-keepers. So far the chances of success with artificial rearing under practical conditions cannot be rated at more then 50%, but doubtless considerable progress will be made within the next few years.

Early weaning, which involves taking the sow away from the litter when the pigs are 10–14 days old, at the earliest, has now been quite satisfactorily carried out under practical pig-keeping conditions. When weaned the pigs are fed on dry meals, crumbs or pellets, water being provided separately.

The main problem connected with early weaning is one of economics, which can be stated simply as "Can we do it better and cheaper than the sow?" The future of this new method will depend on the answer to this query. At the prevailing rather high cost of dry milk substitutes a large-scale application might not always be economic. To overcome this difficulty—and taking into consideration the fact that the younger the pig, when taken away from its mother, the more attention it requires and the more costly is its feeding—several suggestions have been made in favour of weaning when the litter is 3–6 weeks old [13]. This certainly can be done, but the overall advantages appear to be higher the earlier the pigs are weaned. The economics involved in each routine have still be to worked out. It should also be kept in mind that with methods adopted at present the pigs, when weaned, suffer some setbacks, the severity of which is smaller the higher the age at weaning. In general, weight, vigour and overall condition of the piglet, rather than age alone, should be the criteria for the pig's suitability for weaning.

Advantages of the New Methods

From the description of the two methods it is obvious that whereas artificial rearing may eventually provide *all* the answers to the shortcomings of the orthodox method of rearing (points 1–9, p. 176), early weaning can solve only *some* of them (points 5–9, p. 176). In addition the following advantages have been claimed for both methods:

1. Heavier and more uniform pigs at 8 weeks of age.
2. No "runt" pigs.
3. Fewer setbacks during the normal suckling and the immediate post-weaning periods.
4. Advantage accruing from high efficiency of food conversion in the young pig. (A pig aged 1–8 weeks will put on 1 lb. of gain for about 1·5–2 lb. of feed.)
5. Possibility of producing more than two litters per sow per year.
6. Better control of disease, including the possibility of producing "disease-free" pigs by removing them at birth and rearing them artificially [31]. Successful attempts to free herds from atrophic rhinitis and virus pneumonia have already been reported.
7. Sows can be marketed in good condition following the early weaning.
8. Saving in labour, by reducing the volume of feed, bedding and manure handling necessary for sows nursing litters.
9. Increased turnover, resulting in lower overhead costs.

COMPOSITION OF MILK SUBSTITUTES

No agreement has yet been reached as to the most suitable composition for a sow's milk substitute food. The values in Table II show that in

TABLE II

DAILY CONSUMPTION OF NUTRIENTS BY A PIGLET RECEIVING 850 G. SOW'S MILK OR A MILK SUBSTITUTE OF SIMILAR FOOD VALUE

Nutrient	Sow's milk	Milk substitute [14]
Total solids (g.)	169·0	170·0
Fat (g.)	71·0	45·0
Protein (g.)	49·0	51·0
Lactose (g.)	41·0	64·0
Ash (g.)	8·0	10·0
Calcium (g.)	2·1	1·7
Phosphorus (g.)	1·4	1·2
Vitamin A (I.U.)	770·0	850·0
Vitamin D (I.U.)	39·0	85·0
Vitamin C (mg.)	111·0	—
Thiamine (mg.)	575·0	552·0
Riboflavin (mg.)	1165·0	1105·0
Nicotinic acid (mg.)	7106·0	2210·0
Panthotenic acid (mg.)	3630·0	6630·0
Pyridoxin (mg.)	170·0	552·0
Biotin (mg.)	12·0	8·5
Vitamin B_{12} (mg.)	1·4	—

the early preparations an endeavour was made to approximate the composition of the substitute to that of the natural product and to correct some of its known deficiencies. The optimum nutritional requirements for growth of piglets have not yet been ascertained, and the current tendency in formulating the milk substitutes is to provide, as far as each nutrient is concerned, a very wide margin of safety which will guard against running into a specific deficiency. Doubtless the quantities of some of the individual nutrients will eventually be considerably reduced without any detrimental effects to the pig—a development that will lower the cost of milk substitutes. At present the formulae of most of the substitutes that have given reasonable results have been arrived at empirically.

Table III gives the ranges in the chemical composition of rations, the details of which have appeared in print. It shows that divergent opinions exist on the subject. In Tables IV and V a few examples are given of mixtures for artificial rearing and early weaning. They demonstrate clearly that a desired chemical composition can be achieved by using a great variety of ingredients. In general, experience indicates that whereas expensive purified ingredients may be essential in milk substitutes for artificial rearing, cheap and crude feeds may be satisfactory for early weaning mixtures. Further research will undoubtedly result in simplification of the rather involved formulae.

During the last few years research workers throughout the world have been attempting to collect data on which modifications in the empirical formulae can be based. Some have studied the nutritional requirements of the piglet, while others have concentrated on studying the value of potential components of milk substitutes. Investigations have also been made on how to improve the palatability of the mixtures, and on the value of various growth stimulants and protective agents. It is outside the scope of this article to go into details of all this work, but brief reference may be made to a few of the problems studied.

TABLE III

RANGE OF VARIATION IN CHEMICAL COMPOSITION OF RATIONS FOR ARTIFICIAL REARING AND EARLY WEANING

Constituent	Artificial rearing (%)	Early weaning (%)
Crude protein	26·0–34·0	23·5–32·0
Fat	8·5–11·1	3·0–8·0
Crude fibre	—	0·2–1·0
Non-nitrogenous extract	50·4–57·5	51·1–61·5
Ash	6·0–6·6	6·0–11·1

Problems in Formulation

Almost all milk substitutes include an antibiotic in their formulae; indeed, it may be said that the advent of antibiotics made the artificial rearing of pigs possible. The major function of the antibiotic in milk substitutes is to protect the young pig from many infections that challenge it during the early days of its life. There is no doubt that the growth-promoting properties of the antibiotics also play their part. Chlortetracycline or oxytetracycline

TABLE IV

EXAMPLES OF RATIONS FOR ARTIFICIAL FEEDING

	%
Ration A—U.K. N.I.R.D. (unpublished)	
Dried skim milk	68·7
Glucose	15·1
Arachis oil + emulsifier	9·9
Calcium caseinate	2·6
Dried yeast	2·0
Bone meal	1·7
Minerals (6 ingredients)	—
Vitamins (12 ingredients)	—
Procaine penicillin or Aurofac	—
Ration B—U.S.A. Johnson *et al.* [14]	%
Casein (vitamin-free)	30·0
Glucose	37·4
Lard	26·6
Minerals (12 ingredients)	6·0
Vitamins (14 ingredients)	—
Ration C—Sweden Dyrendahl *et al.* [10]	%
Dried skim milk	76·0
Lard	5·0
Rapeseed oil	5·0
Lecithin	1·0
Dried yeast	3·0
Glucose	5·0
Cane sugar	5·0
Minerals (5 ingredients)	—
Vitamins (9 ingredients)	—
Terramycin	—

and procaine penicillin are widely used. The amount of antibiotics used in milk substitutes varies considerably, but the generally accepted level per ton of air-dry food mixture is 30–50 g.

The concentration of total solids in the liquid milk substitutes remains a matter of controversy. Sow's milk contains about 20% of total solids, but some experimental results indicate that lower concentrations, say 15%, may be preferable in milk substitutes [6, 19]. This problem of total solids may be connected with the observation made at Shinfield that the baby pig, much as the older one, is apt to overeat when fed *ad lib.*, and that some kind of restriction may be advisable, even in the very early stages.

TABLE V

EXAMPLES OF RATIONS FOR EARLY WEANING

Ration A—U.K. N.I.R.D. (unpublished)	
	%
Dried skim milk	5·0
Oat flour	20·5
Wheat flour	40·2
White fish meal	17·9
Dried yeast	2·7
Molasses	6·7
Arachis oil	5·0
Minerals (6 ingredients) Vitamins (12 ingredients)	2·0
Procaine penicillin or Aurofac	—
Ration B—U.K. Rowett Res. Inst. [26]	
	%
Dried skim milk	42·0
Cane sugar	10·0
Rolled oat groats	22·0
White fish meal	15·0
Dried yeast (unextracted)	5·0
Salt	0·5
Trace minerals (8 ingredients)	1·0
Cod liver oil	2·0
Vitamins (2 ingredients)	—
Aurofac 2A	2·5
Ration C—New Zealand Smith [25]	
	%
Buttermilk powder	65·0
Wheat meal	10·0
Maize meal	7·0
Meat meal	10·0
Sugar	8·0
Plus per 100 lb. of mix:	
Salt	8 oz.
Ferrous sulphate	2 oz.
Vitamins (3 ingredients)	—
Aurofac 2A	1 lb.

The level of protein that should be present in milk substitutes has received much attention [2, 7, 8, 11, 20–23], and one report [20] gives details of individual amino-acids required. Studies have also been made on the level of fat [3, 6–8, 10, 11, 19, 20] and on the nature of the carbohydrates in the milk substitute mixtures [11, 17, 21, 30].

A most interesting development has been reported by workers from the Iowa State Agricultural College [18], and more recently by Canadian workers [15]. These workers stressed the importance of the activity of various enzymes in the body on the utilization of nutrients by the baby pig. Evidence is presented that some of the enzymes may not develop until the pig is a few weeks old, so that a newborn or very young animal may not be able to break down some of the components of the diet—a prerequisite to normal digestion. For example, the pig may be able to utilize the protein of milk, whereas it is apparently unable to make use of soya bean protein efficiently until it is five weeks old. Of significance in this connection is the finding by the Russian workers Kvasnitskii and Bakeeva [16] that hydrochloric acid does not appear in the stomach until the piglet is 20–30 days of age, and they claim that although pepsin is present early in life, the enzyme is not utilized until this acid is formed.

The fact that some enzyme systems develop later than others may explain reported differences in the suitability of various carbohydrates for pigs of different ages. It may well be that one type of carbohydrate is satisfactory for the first few days of life while another is not and should only be used after the pig is 3–4 weeks old, when the relevant enzyme has started to function. Our knowledge in this interesting field is very limited, but it is already evident that much more attention will have to be paid to the enzyme system in the pig and to the possibility of augmenting its functioning by including enzymes in milk substitutes.

It has now been established that pigs consume milk substitutes more readily when these are sweetened by the addition of sugar. The sugar also acts as a useful source of energy [17].

Vitamins and minerals have received less attention because, as already mentioned, the prevailing tendency is to include every substance of the kind that could conceivably be needed, at levels providing a wide margin of safety. In practice this means that as many as 24–40 ingredients may be added to cover the vitamin and mineral requirements of the baby pig. For example, Johnson *et al.* [14] use a ration for artificial rearing containing these salts: CaHPO, K_2HPO_4, $CaCO_3$, NaCl, $MgSO_4$, Ferric citrate, $MnSO_4$, KI, CaF_2, $CuSO_4$, $ZnCl_2$ and $COCl_2$, and vitamins A, D, E, K, thiamine, riboflavin, pyridoxin, nicotinic acid, pantothenic acid, inositol, paraminobenzoic acid, choline, folic acid and biotin. Quantitative details of the supplements used in the rations exemplified in Tables IV and V will be found in the works cited.

The preparation of milk substitutes is beyond the capacity of pig-keepers and must be left to organizations possessing the required facilities and techniques. Several proprietary sow-milk substitutes are already on the market in Great Britain. Their merits cannot be discussed here, but their future will naturally depend on their nutritional adequacy, which must remain the primary consideration, and on the price at which they are sold.

OTHER CONSIDERATIONS

In considering the economics of the new methods account must be taken not only of the feeding aspect, but of many other features involved in rearing. With artificial rearing the main saving is in preventing what would otherwise amount to a total loss. This applies to surplus pigs, orphan pigs, pigs starved owing to lack of milk in the sow, and pigs crushed by the sow during the first few days of life. Early weaning, of course, does not cover this aspect at all, and perhaps its main economic advantage lies in the fact that the sow is available for mating soon after the piglets have been taken away.

Mating Problems

Availability of the sow for early mating is also an economic feature in artificial rearing, and it is therefore important to know the relevant facts established to date. There appear to be no difficulties due to weaning the litter from the sow, even at the time when she is in full lactation. A sow removed from her litter 1–10 days after farrowing will settle down without any untoward effects, and no treatment is required; but following the abrupt weaning the amount of food given to the sow must be reduced immediately to a level covering only the maintenance requirement. During the first few days after parturition a sow will stand to a service by the boar. It has, however, been demonstrated that such an early mating will usually be ineffective: apparently the chances of ovulation at this stage are small. Normal service, giving reasonable chances of conception, can take place about 15–20 days after parturition.

This means that the idea of producing three litters in a year from one sow can no longer be entertained. It originated from a simple calculation that a saving of two lactations, amounting to 112 days, would leave just sufficient time for a third gestation period. It appears, however, that the reasonable saving to be expected, without jeopardizing the fertility of the sow, is about 90–100 days. In theory, this would allow 2¾ litters to be produced in the year, but taking other complications into account a safer figure would be 2½ litters, giving the substantial increase of 20% in productivity of the sow.

The earliest time for mating should be 15–18 days after parturition, irrespective of the time of the removal of the pigs. A careful watch must be kept for signs of heat, which are less pronounced than those following a weaning at 8 weeks.

Environmental Conditions

Very little is known about the environmental conditions needed to obtain optimum results with the new methods. For artificial rearing some type of brooder seems to be essential. It is usually said that a temperature of about 85° F should be provided when the pigs are a few days old and that it can be reduced as they age. Infra-red lamps are generally used to provide a small area with a higher temperature, while other means of heating keep the room around 65° F. For early weaning, conditions are much less exacting; the warmth of the well-conditioned farrowing house is adequate, and the only effort required is to avoid the temperature falling below 60° F. The temperatures quoted are based on practical experience, and the whole subject calls for an early scientific enquiry.

Generally speaking, the new rearing methods should only be attempted by breeders who have good housing facilities. With the early weaning method it appears to be an advantage to rear the pigs out of doors on grass during the warmer parts of the year.

Detrimental Effects

Finally, attention may be directed to two major problems that await further research. The long-term effects of artificial rearing and early weaning on the reproductive capacity of the sow are not yet fully known. Evidence is accumulating that there are few, if any, detrimental effects, and some records show that sows subjected to the new routine produced up to eight normal litters. Nevertheless this aspect calls for continued vigilance.

The other problem, which is much more serious, concerns the effect that the new rearing routines may have on subsequent fattening. There are indications that when some pigs reared in these ways reach bacon weight they grade badly for carcass quality: in several instances the pigs appeared to be too fat when 8–10 weeks old, and the over-fatness persisted right up to the time of slaughter, resulting in a down-grading of the carcass. Far too little is known as yet about the many and varied factors which may be contributing to this situation; but attention must be focused on this problem, since the future of the new methods will depend on our ability to ensure that they do not induce detrimental effects on carcass quality. It is possible that the normal fattening routine may have to be modified to fit the new rearing methods. Clearly we have still a lot to learn before the green signal for a general go-ahead can be given.

REFERENCES

[1] Bailey, C. B., Kitts, W. D. and Wood, A. J. (1956). *Canad. J. Agric. Sci.*, **36**, 51.

[2] Becker, D. E., Ullrey, D. E. and Terrill, S. W. (1954). *J. Anim. Sci.*, **13**, 346.

[3] Becker, D. E., Ullrey, D. E. and Terrill, S. W. (1954). *Arch. Biochem. and Biophys.*, **48**, 178.

[4] Braude, R., Coates, M. E., Henry, K. M., Kon, S. K., Rowland, S. J., Thompson, S. Y. and Walker, D. M. (1947). *Brit. J. Nutr.*, **1**, 64.

[5] Bustad, L. K., Ham, W. E. and Cunha, T. J. (1948). *Arch. Biochem.*, **17**, 249.

[6] Catron, D. V., Nelson, L. F., Ashton, G. C. and Maddock, H. M. (1953). *J. Anim. Sci.*, **12**, 62.

[7] Crampton, E. W. and Ness, O. M. (1954). *J. Anim. Sci.*, **13**, 357.

[8] Crane, F. M. (1953). *J. Anim. Sci.*, **12**, 912.

[9] Done, J. T. (1955). *Vet. Rec.*, **67**, 623.

[10] Dyrendahl, S., Swahn, O., Bjorck, G. and Hellving, L. (1953). *Acta Agr. Scand.*, **3**, 334.

[11] Hanson, L. E., Rutledge, E. A. and Ferrin, E. F. (1954). *Minn. Agric. Exp. Sta. Mimeo H*-124 and *Rep.* 32*nd Swine Feeders Day*.

[12] Hoerlin, A. B., Adams, C. H. and Meade, R. J. (1956). *J. Amer. Vet. Med. Assoc.*, **128**, 127.

[13] Jensen, A. H., Terrill, S. W. and Becker, D. E. (1955 and 1956). *Univ. Illinois Swine Growers Day Reports.*

[14] Johnson, B. C., James, M. F. and Krider, J. L. (1948). *J. Anim. Sci.*, **7**, 486.

[15] Kitts, W. D., Bailey, C. B. and Wood, A. J. (1956). *Canad. J. Agric. Sci.*, **36**, 45.

[16] Kvasnitskii, A. V. and Bakeeva, E. N. (1940). *Trud. Inst. svinovd. Kiev*, **15**, 3. (See abstract 1487 in *Vet. Bull.*, **13**, 222.)

[17] Lewis, C. J., Catron, D. V., Combs, G. E., Ashton, G. C. and Culbertson, C. C. (1955). *J. Anim. Sci.*, **14**, 1103.

[18] Lewis, C. J., Catron, D. V., Liu, C. H., Speer, V. C. and Ashton, G. C. (1955). *J. Agric. Fd Chem.*, **3**, 1047.

[19] Nelson, L. F., Ashton, G. C., Maddock, H. M. and Catron, D. V. (1952). *J. Anim. Sci.*, **11**, 771.

[20] Peo, E. R., Ashton, G. C., Speer, V. C. and Catron, D. V. (1954). *J. Anim. Sci.*, **13**, 995.

[21] Pfizer (1953 and 1954). 1*st and* 2*nd Farm and Field Day Reports.*

[22] Reber, E. F., Whitehair, C. K. and MacVicar, R. (1953). *J. Nutr.*, **50**, 451.

[23] Sewell, R. F., Sheffy, B. E., Eggert, R. G. and Loosli, J. K. (1953). *J. Anim. Sci.*, **12**, 597.

[24] Shuman, R. D., Earl, F. L. and Stevenson, J. W. (1956). *J. Amer. Vet. Med. Assoc.*, **128**, 189.

[25] Smith, D. M. (1955). *N.Z. J. Agric.*, **91**, 594.

[26] Smith, H. and Lucas, I. A. M. (1956). *Farm. & Stockbr.*, **70**, No. 3479, p. 49.

[27] Speer, V. C., Ashton, G. C., Diaz, F. and Catron, D. V. (1954). *Iowa Farm Sci.*, **8**, 3.

[28] Thornton, D. D. (1955). M.Sc. Thesis, Wye College, Univ. London.

[29] Whitehair, C. K. and Thompson, C. M. (1956). *J. Amer. Vet. Med. Assoc.*, **128**, 94.

[30] Wise, M. B., Barrick, E. R., Wise, G. H. and Osborne, J. C. (1954). *J. Anim. Sci.*, **13**, 365.

[31] Young, G. A., Jr., and Underdahl, N. R. (1951). *Arch. Biochem.*, **32**, 449.

[32] Young, G. A., Jr., and Underdahl, N. R. (1955). *Amer. J. Vet. Res.*, **16**, 123.

WORLD ASPECTS OF PLANT PROTECTION

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Since 1945 several important international and regional agreements have been made on such broad aspects of plant protection as quarantine regulations and the provision of mutual aid in dealing with certain destructive pests and pathogens. These achievements are discussed in this paper, which is a shortened form of a conference address. A full account is published in Plant Protection Conference, 1956, reviewed on page 213 of this issue.

The Food and Agriculture Organization of the United Nations has, as one of its major functions, the promotion of agricultural production. To achieve this objective the importance of plant protection cannot be overstressed. Not only must the world produce more, but it must save what it produces.

Plant protection aspects are diversified and dynamic. The change in the balance of nature, the progress of sciences, the modification of agricultural systems, and other human efforts all bring about changes to the problems involved. In this brief statement, however, it is proposed to review only some of the leading problems requiring more international action and the major advances which have been made towards this end.

THE DEVELOPMENT OF INTERNATIONAL CO-OPERATION

Early Efforts

The Phylloxera Convention, which was signed on 3rd November 1881 by five European countries, was probably the first concrete action leading to inter-governmental collaboration in the field of plant protection. During the twenty years following the introduction of grape phylloxera about 1859 from North America to France, the pest became widely established in Central Europe. The importance of the wine industry in many of the affected countries led to a great deal of activity in the study of control, and much thought was given to the possibility of preventing further introductions and spread by quarantine regulations. Such thought and proposals reached a final and official status in the Phylloxera Convention, the result of the work of an international conference held at Berne, Switzerland.

Proposals to promote international co-operation in the broader aspects of plant protection can be traced back also to the same period. Dr. Jacob Eriksson, the eminent Swedish botanist, laid a plan for international action before the International Congress for Agriculture and Forestry at Vienna in 1881. In 1891, at the International Congress at The Hague, Professor Rostrup of Denmark called attention to the need for means for preventing the spread of epidemic diseases through the movement of infected plants or seeds. The matter was discussed again in two following sessions of the International Congress for Agriculture and in 1903 a special committee on phytopathology was formed, composed of representatives from several countries and headed by Dr. Paul Sorauer, whose *Zeitschrift für Pflanzenkrankheiten* was made the official organ.

In 1905 the former International Institute of Agriculture was founded at Rome, one of its objectives being the better control of plant diseases and pests. Among other activities, the Institute published from 1927 to 1946 the *International Bulletin of Plant Protection* to facilitate the dissemination of information.

Dr. Eriksson presented his proposal further at several successive international meetings, and action was finally taken by the International Conference of Phytopathology held in Rome in 1914. The Conference adopted a final Act, providing the ground for international co-operation for combating plant diseases and pests. Unfortunately the creation of this Act was followed almost immediately by the first world war, and consequently it was never put into effect. It was only after a long lapse that the Act received attention again through proposals for its revival and modification. An international meeting, held under the auspices of the International Institute of Agriculture in April 1929, adopted a draft Convention Internationale pour la Protection des Végétaux which was signed by twenty-six participating countries. Of these, sixteen countries ratified the Convention and later six additional countries adhered to it. This Convention remained in force until 1951, when it was replaced by a new one.

Locusts have long been recognized to demand international action, but early attempts to create international agencies and agreements to effect their control proved abortive. An international conference in Rome in 1920 failed in its attempt to form a commission for defence against locusts and only adopted a draft convention pledging signatories to take measures against locusts, to exchange information and submit reports to the International Institute of Agriculture. This somewhat unrealistic convention, signed by ten States, resulted in no practical value.

In 1926 five Near East governments concluded an agreement to establish and maintain an International Office of Intelligence on Locusts at Damascus. For several years the office assembled information on the Moroccan and desert locusts, but eventually through lack of adequate support it ceased to function. The Locust Information Bureau for Africa, recommended in 1929, and the Southern African Locust Information Bureau, proposed in 1934, never materialized.

The greatly improved knowledge of the various locust problems accumulated through the years led towards the demise of world locust conferences and focused attention on the need to explore the subject on a regional basis, and for specific international action. This concept, which may be said to date from the Fifth International Anti-Locust Conference, Brussels, 1938, resulted in international agreements of such practical value as to transform the whole idea of locust control in Africa and the Near East, although their formal adoption was delayed by the war.

The foregoing reviews briefly the earlier efforts in promoting inter-governmental co-operation. Collaboration between individual plant pathologists and entomologists, of course, dates perhaps as far back as the founding of the sciences of plant protection. The International Botanical Congress had its first session in 1864 in Brussels, although phytopathological topics were seldom included in the programmes of earliest sessions. The International Entomological Congress also has a history of over fifty years.

Post-war Progress

After the second world war plant protection received far greater attention than ever before. This progress was due to many factors, among which the following were perhaps the most important.

First, one of the effects of the war was to enhance the destructiveness of plant pests and diseases and to facilitate their spread as a result of the continued neglect of proper cultural practices and sanitation measures. Consequently during the post-war struggle for more efficient crop production plant protection became an important part of agricultural rehabilitation.

Second, the increased range and speed of modern transportation not only improved contacts between countries and peoples, but also rendered natural barriers unreliable against the movement of harmful pests and diseases. The drastic outbreaks in recent years of several pests and diseases made many countries aware of the increased danger and the need for closer co-operation.

Third, the discovery of the value of synthetic organic pesticides of high potency, such as DDT, BHC, MCPA and 2,4-D, greatly contributed to the widespread consciousness of plant protection.

This increased appreciation of the importance of plant protection is fully reflected in the work of inter-governmental agencies and international technical assistance programmes. The Food and Agriculture Organization (FAO), a specialized agency of the United Nations coming into existence in October 1945, has from its beginning included plant protection as a major phase of its programme. In realizing that most pest and disease problems are regional in nature, FAO has encouraged its member governments to form regional plant protection organizations as co-ordinating or advisory bodies.

Other international agencies have also engaged actively in promoting plant protection programmes. In addition, there are bilateral agreements between governments for the provision of technical assistance in plant protection and for the adoption of common measures in the control of pests and diseases. Some of these international agencies and their activities and programmes will be mentioned later.

PLANT PESTS AND DISEASES OF INTERNATIONAL IMPORTANCE

Recent Spread of Pests and Diseases

During recent years some noteworthy outbreaks of destructive plant pests and diseases, in areas previously free, have caused great concern and are likely to be a heavy burden both to governments and growers for many years to come.

Among plant diseases the spectacular occurrence of the maize rust (*Puccinia polysora*) in Africa typifies what a relatively insignificant pathogen can do in new environments. This rust apparently never inflicted severe losses in its indigenous land,* but when it was found in Sierra Leone in 1949 its violence caused great alarm. From Sierra Leone, it spread rapidly across Central Africa and in several years reached islands in the Indian Ocean. Its effect on maize is so devastating that the West African Governments had to import maize to meet the losses inflicted. It is likely that the disease will eventually cover the whole of Africa and become a threat to the Asiatic mainland.

Tristeza or quick decline of citrus is another old disease which thrived in a new home. This disease did not receive great attention until, in the early 1930s, it appeared in South America, where in less than two decades it destroyed most commercial citrus plantings established on the susceptible sour-orange rootstock in some parts of Brazil and Argentina.

The tea industry in south-east Asia has had much to contend with since blister blight (*Exobasidium vexans*) spread from India to Ceylon, Malaya and Indonesia between 1946 and 1951. Chile, one of the most ancient potato-growing countries, was not confronted with the problem of late blight (*Phytophthora infestans*) until 1950, and British Guiana had to search for new sugar cane varieties after the invasion of leaf scald (*Xanthomonas albilineans*) around 1951.

Among insect pests, fall webworm (*Hyphantria cunea*), a rather unimportant pest in North America, was found in Europe—first in Hungary—during the last war. After the war it spread into Czechoslovakia, Yugoslavia and Austria and has become a very serious hazard to fruit and forest trees. Its great damage to mulberry brought a new threat to the silk industry in south Europe.

The Mediterranean fruit fly (*Ceratitis capitata*) was found for the first time in Costa Rica in 1955 and soon became established on the central plateau in a large area. The possibility of it damaging coffee berries caused great concern to every country in Central America.

One of the worst pests of stored grain, the khapra beetle (*Trogoderma granarium*), suddenly appeared during the past few years in widely separated areas of the world, such as Rhodesia, Italy and the United States. Undoubtedly much effort will be needed to achieve its eradication.

From these examples it becomes evident that there is a need for more efficient international co-operation and better knowledge on the biology of plant pests and diseases in order to deter their spread. The introduction of some of the pests and diseases mentioned above obviously could be prevented by effective plant quarantine measures. Others, such as the maize rust, would require in addition a better understanding of their pathogenicity and ecological requirements. For a disease like blister blight, which is disseminated by airborne spores, the only hope lies in an effective and thorough control programme in the countries where it occurs.

Diseases and Pests of Potential Danger

There are many destructive diseases and pests which are still limited in geographical distribution and their introduction into other parts of the world would probably inflict disastrous losses. The greatest danger appears to exist with some diseases affecting tree crops, because of the difficulties involved in controlling them, in the development of resistant strains and in rehabilitating the ruined plantings. For instance, the South American leaf blight (*Dothidella ulei*), which has been a major handicap to the successful establishment of Hevea rubber in the American tropics, is not yet known to occur in south-east Asia. On the other hand, *Oidium heveae*, a destructive pathogen of the Old World, is an equal danger to American rubber planters. A similar situation exists with regard to coffee and cacao. Their respective worst enemies are American leaf spot (*Mycena citricolor*) and witches' broom (*Marasmius perniciosus*) in the New World, and the rust (*Hemileia vastatrix*) and the virulent swollen-shoot virus in the Old World.

Sugar cane has many diseases destructive enough to ruin a promising crop. Against their introduction most stringent measures have been undertaken by all major cane-growing countries. The costs and efforts required in carrying out the recent eradication campaigns in Australia to eliminate some diseases provide ample justification for future precautions. Those dangerous diseases which are still not widely distributed include downy mildew (*Sclerospora sacchari*), gumming diseases (*Xanthomonas vasculorum*), and virus diseases known as sereh, streak, Fiji and ratoon-stunting diseases.

Among diseases of other crops, the introduction of downy mildew (*Peronospora tabacina*) would be a danger to tobacco culture in the Mediterranean and Africa, and so would bunchy top to the banana industry in the American tropics and curly top to beet cultivation in Europe. North America and Europe both have some dangerous virus diseases of fruit trees of their own, and golden nematode of potato (*Heterodera rostochiensis*) is a major quarantine problem to many countries.

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* Central and South America.—Ed.

For insect pests a much longer list can doubtless be compiled for quarantine regulations of various countries. Take the more important cotton insects. The false pink bollworm (*Sacadodes piralis*), boll weevil (*Anthonomus grandis*), and leafworm (*Alabama argillacea*) are still restricted to certain parts of America; the Queensland pink worm (*Platyedra scutigera*) occurs only in Australia and New Guinea; spiny bollworm (*Earias insulana*) and cotton worm (*Prodenia litura*) are pests of the Old World. Even a widely distributed species like pink bollworm (*Platyedra gossypiella*) has not yet appeared in Central America.

The two African capsid bugs *Sahlbergella singularis* and *Distantiella theobroma* and the *Helopeltis* species of Ceylon and Java are indeed not to be welcomed by other cacao-producing countries. The Mediterranean area has some insects, such as *Lixus* and *Cleonus*, which are among the worst enemies of beet culture. Furthermore, various species of fruit flies and stem borers affecting sugar cane and cereals demand the constant vigilance of quarantine inspectors of many countries, and there is no reason to believe that Colorado beetle (*Leptinotarsa decemlineata*), Mexican bean beetle (*Epilachna varivestis*) and Japanese beetle (*Popillia japonica*) cannot extend beyond their present geographical range.

The spread of weeds does not seem to have received full attention, but the potential danger is equally great. The damage that the Russian halogeton (*Halogeton glomeratus*) caused in the United States is a good example.

CURRENT INTERNATIONAL ACTIVITIES

International Plant Protection Convention

The need for a new broad international agreement on plant protection to meet the ever-changing conditions and to replace the obsolete conventions was first proposed by the FAO Conference in 1949. A draft International Plant Protection Convention was accordingly prepared and, after being several times revised, was approved by the FAO Conference in 1951 and came into force on 3rd April 1952. It has now been signed by thirty-seven governments and adhered to by a number of others.

The Convention, which aims at furthering international co-operation and promoting national activities, provides a broad framework adaptable to changing conditions. Within its framework supplementary agreements concerning specific areas or specific problems of international importance may be formulated. To remedy the existing diverse quarantine requirements imposed by different countries, uniform regulations and procedures and a model phytosanitary certificate are provided. The contracting governments also agree to set up satisfactory national services, to establish regional plant protection agencies, and to participate in international control compaigns during emergency outbreaks. For disseminating information on the occurrence, outbreak and spread of plant pests and diseases of economic importance a World Reporting Service was organized. The information received is published in a monthly periodical entitled *FAO Plant Protection Bulletin* and is also regularly transmitted to governments concerned by other means.

Regional Agreements

This effort is greatly strengthened by a number of regional agreements. In Europe the Convention for the Establishment of the European and Mediterranean Plant Protection Organization (EPPO) was concluded on 18th April 1951 and has been signed by twenty-two governments. It has since established a regional reporting system as a part of FAO's World Reporting Service and has convened many technical meetings to study quarantine problems and measures for combating important pests, such as the Mediterranean fruit fly, San José scale, storage pests, potato root eelworm, muskrat and citrus diseases.

In Central America, Mexico and Panama the Organismo Internacional Regional de Sanidad Agropecuaria (OIRSA), which came into existence in July 1955, has concentrated its initial efforts in assisting governments to build up quarantine services, to control locusts and the Mediterranean fruit fly, and to organize pest and disease surveys.

The Inter-American Plant Sanitation Convention, concluded on 24th September 1948 and signed by four South American Governments, deals mainly with plant quarantine matters, but its provisions do not appear to have been fully implemented.

The Plant Protection Agreement for the South East Asia and Pacific Region, which was approved by the FAO Council on 26th November 1955, is now open for signature by governments involved. It is aimed at preventing the introduction and movement of destructive plant diseases and pests, and provides for the establishment of a regional committee as an advisory body to participating governments on procedures and arrangements.

The Phyto-sanitary Convention for Africa South of the Sahara, negotiated by the Commission for Technical Co-operation in Africa South of the Sahara (CCTA), has been signed by six governments and is in the process of ratification. It has similiar objectives to the South East Asia Agreement and provides for the establishment of a permanent commission to consider measures of protection needed and a committee of information.

International Campaigns for Locust Control

The control of migratory locusts is a typical international problem. To suppress existing plagues and to prevent future outbreaks, concerted action by all affected countries is needed.

One of the most important locust species is the desert locust (*Schistocerea gregaria*), which threatens agricultural production in a vast belt extending from western Africa through the Near East to India. International co-operation in its control has been firmly established for many years, but since the present plague commenced about 1948–49 joint action has been greatly intensified. Since 1951 FAO has assumed the responsibility of appraising the over-all situation of the desert-locust plague and of co-ordinating control campaigns in certain key areas. By its provision of technical staff, equipment and insecticides FAO also contributed directly to the campaigns which succeeded in preventing extensive crop losses. Anti-locust units from seven countries and FAO participated in the 1953–54 campaign and several other governments contributed materials or funds. The cost of the 1954–55 campaign in the Arabian Peninsula, amounting to about U.S. $1,300,000, was met by contributions from sixteen governments and by the Arab League and FAO. Similar action was taken during the past season. These campaigns, while not eliminating the desert-locust plague, have clearly demonstrated what can be achieved through co-operative action in checking the locusts' spread. It is recognized, however, that it is more important to prevent future plagues than to check existing ones. For this, international co-operation will be equally indispensable, and FAO has recently taken steps to initiate a programme towards this end.

Similar international actions have been successful in combating other locusts. The international organization, established in 1944 as a result of an agreement among five governments for the permanent control of the red locust (*Nomadacris septemfasciata*), has prevented several incipient outbreaks in Northern Rhodesia and Tanganyika which might have involved most of Africa south of the Sahara in serious locust invasions.

The earlier exploratory work in Africa not only located outbreak areas of the red locust, but also identified on the river Niger in the French Sudan what appears to be the only outbreak area of the African migratory locust (*Locusta migratoria migratorioides*). This discovery led to the establishment of a supervision centre on the Niger, under the general direction of an international Council financed by three governments. Preventive service is maintained by the centre and has achieved notable success through its suppression of several outbreaks.

In Central America the International Committee of Co-ordination for Locust Control, established in 1949, successfully brought the last major locust outbreak to an end. Through assistance provided by FAO, the life cycle and phase transformation of the most important species, tentatively classified as *Schistocerca paranensis*, was clarified and the main outbreak areas were defined. Those activities are now being continued by the OIRSA.

The South American locust (*Schistocerca parenensis*) is a serious menace in Argentina, Bolivia, Brazil, Paraguay and Uruguay, and the present plague has been continuing unabated since 1943. The Permanent Inter-American Anti-Locust Committee, created in 1946, has been active since 1948 in the circulation of information on swarm movements and has commenced studies to delineate outbreak areas. Lack of adequate funds has hitherto prevented the Committee from furnishing material assistance to the affected countries.

Other International Campaigns

Many other dangerous plant pests have been successfully controlled or their spread has been prevented through international efforts. For instance, in the control of fall webworm Yugoslavia and Austria have been assisted by tangible offers from EPPO and certain European governments and FAO has provided financial and technical aid to initiate work on biological control and to develop intensive research. To prevent the spread of the Colorado beetle in Western Europe EPPO has maintained international control compaigns in some areas of strategic importance. The olive fly

(*Dacus oleae*) costs the olive growers in the Mediterranean area at least 25% of their harvest in a normal year. Effective chemical methods for its control were devised only through a co-operative research project initiated in 1953 by a working party sponsored by FAO. In Central America the control of the Mediterranean fruit fly is regarded as an international problem of great importance. Governments in the region have provided, through OIRSA, material assistance, and the U.S. Government has furnished experts to supervise the control operations. In Africa CCTA has made efforts to promote control measures against the grain-eating weaver bird (*Quelea quelea aethiopica*).

In the Pacific region, rhinoceros beetle (*Oryctes rhinoceros*), which destroyed 50% of coconut palms in ten years in the Palaus and eliminated practically all bearing trees in some other islands, is the subject of an area-wide campaign initiated by the South Pacific Commission.

For the development of disease-resistant varieties, international wheat and barley nurseries are being maintained in the Near East by FAO and in Latin America by the U.S. Department of Agriculture, in co-operation with the governments involved. The control of cacao diseases is one of the projects organized by the Inter-American Institute of Agricultural Sciences covering the whole of the American tropics.

Technical Assistance Programmes

After the war the need for developing agricultural and other resources in many parts of the world has been fully recognized. Consequently international programmes to effect mutual aid on technical problems flourish.

Under the Expanded Technical Assistance Programme of the United Nations FAO has provided the services of a large number of agricultural and food experts to advise and assist governments either in the organization or planning of a plant protection programme or in the investigation of a specific problem.

Similar programmes are also being carried out through bilateral agreements between governments. In particular, the U.S. Point Four Programme and the Colombo Plan initiated by the British Commonwealth have both contributed greatly to the progress of plant protection. The experts furnished by those programmes are mainly engaged in research and experimental work on plant pests and diseases. Training of local students is an important phase of all those programmes.

The Commonwealth Institutes of Entomology and Mycology, in addition to their valuable services in the publication of their review journals and distribution maps, maintain pools of entomologists and pathologists who can be made available to the Commonwealth Governments whenever important problems arise. The Commonwealth Institute of Biological Control, which has stations in Switzerland, Trinidad and India, is engaged not only in the collection and supply of parasites and predators but carries out operations on biological control in some territories. Its services often also extend to countries outside the Commonwealth.

In addition, commendable contributions towards the achievement of the same purpose have been made by private enterprises, for instance the agricultural programme in Mexico organized by the Rockefeller Foundation, the notable accomplishments of which include the development of rust-resistant wheat varieties and the control of bean diseases and pests.

CONCLUSION

In conclusion, I should like to mention a problem which I personally feel is of basic importance. When we talk about plant protection, we naturally think of the establishment of national agencies, the development of pesticides and resistant varieties, the assembling of information, the training of personnel, advisory service to growers, etc. But control of pests and diseases cannot be regarded only as the responsibility of government officials, scientists and interested commercial enterprises, and even the co-operation from growers is not sufficient in many cases. The ultimate objectives of plant protection will not be achieved until everyone who consumes plants and plant products understands the problems involved and accepts his or her share of responsibility. Take weed control as an example. The eradication of a destructive weed on any extensive scale requires that every bit of land be kept clean and everyone in the region make an effort to prevent its dissemination. This is also true in the eradication of plant diseases and pests. A barberry bush hidden in someone's back yard may produce inoculum of stem rust enough to ruin hundreds of acres of cereals. To facilitate their dissemination over long distance, man, of course, is always the most effective agent and helpful friend to pathogenes and pests. Therefore plant protection is basically a question of mass education, and our efforts have so far been inadequate in this direction.

PLANT PARASITIC EELWORMS

F. C. Peacock

The study of eelworms has rapidly become an important branch of plant pathology. Many species are now known to be serious parasites of cultivated plants in tropical as well as temperate lands, and our knowledge of eelworm biology has steadily advanced. But attempts at control by breeding resistant plants or by chemical or other measures have met with limited success, and a practical answer to the problem has yet to be found.

So far as is known, *An Account of some New Microsopical Discoveries*, published in London in 1745, contains the first record of an eelworm attacking plants, in its description of a "vibrio" causing galls on the ears of wheat; but nearly a hundred years elapsed before careful studies of eelworms as plant pests were begun. In 1933 Goodey [13] at Rothamsted listed 363 references to plant parasitic eelworms, and by 1952, when a literature survey was completed in America by Chitwood and Oteifa [2], the number had increased to 3400, covering over 100 species known to attack economic crops. The knowledge we now have of these pests has been built up mainly in the last 25 years, and only during the past decade has the magnitude of the problem been realized.

In Britain we are most familiar with the potato-root eelworm. This pest is particularly serious in districts where early potatoes are grown year after year on the same soil; but it is steadily increasing in incidence, and about two-thirds of the arable land in all main potato-growing areas now show some degree of infestation. Annual losses of crop from this eelworm were estimated at £2,000,000 several years ago [16]. The sugar beet eelworm is prevalent in England and is most damaging in the eastern counties. Since the last war root eelworms attacking peas and cereals have spread considerably, and in glasshouses and market gardens much damage is frequently caused by root-knot nematodes and by the chrysanthemum and strawberry leaf eelworms.

In the U.S.A. Steiner [18] has assessed the crop loss due to eelworms at $400–500 million, a quarter to half of which may be due to root-knot nematodes. In Florida, spreading decline of citrus has recently been attributed to the burrowing nematode, and an appropriation of $2 million has been made from State funds towards a control programme. The citrus-root nematode infests about 300,000 acres of citrus in S. California. In Trinidad it is estimated [8] that in the next ten years copra production may be reduced by 20–25% over the whole island owing to a nematode causing "red-ring" disease of coconut. Many other instances are recorded of serious damage by eelworms.

In general eelworms weaken, but do not kill, their host plants; symptoms of attack are those of unthriftiness, dwarfing, wilting, browning of leaves and, with some species, malformation of leaves, stems and roots (Figures 4, 7–12). The way is often paved for secondary fungal infection, and because saprophytic and free-living organisms, including eelworms, abound in the soil and invade the damaged roots diagnosis of eelworm diseases is usually a matter for the specialist. Characteristic of most eelworms, however, is the patchiness of the field infestation, with gradual spreading outwards of the affected area, particularly where monoculture of a suitable host plant is practised (Figures 2, 3). Attack by cyst-forming species may be recognized by the presence of cysts on the roots (Figure 5).

DISTINCTIVE FEATURES

Eelworms belong to the *Nemathelminthes*, a group of bilaterally symmetric, unsegmented organisms, usually bisexual, having a vermiform body circular in cross-section; exceptionally the females of certain highly specialized plant parasites become flask-shaped or spherical.

Soil-inhabiting nematodes may be free-living or parasitic on the roots or shoots of plants; they range in length from 0·1 to 7·0 mm, most plant parasitic species being from 0·5 to 2·0 mm. Free-living forms feed on decaying organic matter, fungi and bacteria, and small invertebrate animals, including other nematodes; they are characterized by an enlarged buccal cavity, which often contains cuticularized hooks or "teeth" for holding and tearing the food, and by a muscular oesophagus provided with simple glands believed to produce a digestive enzyme. Plant parasitic forms differ in possessing a protrusible hollow stylet or spear, often used for puncturing plant cell walls; the oesophagus is simple but has well-developed glands. Figure 1 shows the distinctive features of the two types of nematode.

The oesophagus by muscular contraction draws in food and passes it through the terminal bulb, which usually contains a valve, into the simple intestine and thence to the exterior via the anus. An excretory pore is usually located in the oesophageal region. Some free-living species have an additional median oesophageal bulb or pseudobulb. The most prominent part of the nervous system is a nerve ring encircling the oesophagus. The reproductive organs may be single or paired and are often characteristic for the species, particularly in the male.

It is by observation and measurement of these morphological features that the nematologist determines the identity of an eelworm. Fortunately, of the 5000 species of soil-inhabiting nematodes so far described, only about 100 species are parasitic on plants. Some of the more important pests with the diseases they cause are shown in the table. Plant parasitic eelworms, depending on the degree of host-parasite association, may be sedentary or migratory, and ectoparasitic or endoparasitic in their feeding habits. Many of the ectoparasitic species have only recently been proved to be pathogenic; with others, proof is still lacking. Records of pathogenicity and of geographical distribution often reflect the distribution of nematologists rather than that of nematodes!

BIONOMICS AND LIFE HISTORY

Optimum conditions for plant growth are generally those best suiting the development of the plant parasitic eelworm. Thus soil temperatures of 40° C and above are lethal to most eelworms, but low soil temperatures—even light freezing—are withstood fairly well. Adequate soil moisture is necessary for movement and hence development of eelworms, but some species may enter a dormant phase which is resistant to desiccation: *Anguina tritici*, the wheat-gall eelworm, has been revived after 28 years in a dry condition, and *Tylenchus polyhypnus* has survived for 39 years on rye in a herbarium.

Well-aerated, light soils favour the growth and multiplication of root-feeding eelworms, whereas heavy soils and wet conditions are more suitable for the stem-feeding and leaf-feeding types. A soil *p*H of 3–8 is well tolerated by most species.

Prolonged flooding of ground has been reported on occasion to reduce nematode populations, probably owing to the exclusion of air; in the sea-water floods in Holland in 1946–7 submergence for 17 months greatly reduced but did not eradicate the nematode population of the soil. On the other hand, flood water may transport *Heterodera* cysts, and the spread of root-knot eelworm is often attributed to movement of larvae in irrigation waters. Movement of soil by wind and on implements, boots, plants and the feet of birds, also play their part in the dissemination of eelworm diseases.

The life history of plant parasitic eelworms usually involves five moults, in the course of which the skin and cuticular appendages (i.e. spear or "teeth") are shed and the eelworm increases in size. In migratory parasites, such as the stem-and-bulb eelworm, the larvae resemble the adult except for the lack of genitalia. In the more highly specialized sedentary parasites, typified by the cyst-forming species of *Heterodera*, the sexes become differentiated at an early stage and the female gradually loses its worm-like form, becoming flask-shaped and finally spherical.

The cyst which forms the resting stage of this eelworm is the defunct body of the mature female, containing some 200–500 eggs. Within this cyst eggs may lie dormant for as long as 10 years or until stimulated to hatch by the presence in the soil water of a substance which diffuses from the roots of certain plants, for example the potato, tomato and certain grasses in the case of the potato-root eelworm (*H. rostochiensis*).

Larvae are attracted chemotropically to the host root which they penetrate, most often just behind the growing region of the root tip. They then make their way to the pericycle surrounding the central vascular tissues and undergo four moults, during which the larvae of both sexes become spindle-shaped but remain superficially alike. From then on the female swells without further moulting, and this ruptures the epidermis of the root and leaves her body outside with only the head in the tissues; meanwhile the development of eggs inside the female obliterates all other organs, and the body wall becomes tough and easily dislodged from the root. In contrast, the male moults once more and emerges as a long filiform worm which immediately leaves the root for the surrounding soil, fertilizes the female and dies shortly afterwards.

In the potato-root eelworm the whole sequence takes 8–10 weeks, depending principally on temperature and the host plant, and there is normally only one generation in one season. The beet eelworm (*H. schachtii*) develops somewhat quicker, and a second or even a third generation may be produced.

NOTABLE SPECIES OF PLANT PARASITIC EELWORMS

Species	Common name	Disease and main hosts	Distribution
TYLENCHIDAE			
Anguina tritici	Wheat-gall nematode	Ear cockle of cereals	World-wide
Ditylenchus destructor	Potato-tuber eelworm	Tuber-rot of potato	Europe, N. America
,, *dipsaci*	Stem-and-bulb eelworm	Clover sickness, tulip-root of oats, onion bloat, brown-ring of bulbs	World-wide
Tylenchus spp.	—	Pathogenicity not proved.	,,
Tylenchulus semipenetrans	Citrus-root nematode	Quick decline of citrus	U.S.A., Australia, S. Africa, Brazil
HETERODERIDAE			
Heterodera cruciferae	Cabbage-root eelworm	Brassicae	U.K., U.S.A.
,, *glycines*	Soya bean eelworm	Soya bean	U.S.A.
,, *gottingiana*	Pea eelworm	Peas, beans, vetches	Europe
,, *major*	Cereal-root nematode	Cereals, grasses	Europe, Canada, Australia
,, *rostochiensis*	Potato-root eelworm	Potato, tomato	Europe, Israel, Algeria, U.S.A. (Long Island)
,, *schachtii*	Sugar beet eelworm	Sugar beet	Europe, U.S.A.
Hoplolaimus spp.	Lance eelworm	Banana, yam	Jamaica, Hawaii
Meloidogyne arenaria	Root-knot eelworm	Most crops	World-wide
,, *brevicauda*	,, ,,	Tea	Ceylon
,, *exigua*	,, ,,	Coffee	Brazil
,, *hapla*	,, ,,	Most crops	World-wide
,, *incognita*	,, ,,	,, ,,	,,
,, *javanica*	,, ,,	,, ,,	,,
Nacobbus dorsalis	—	Sugar beet	U.S.A.
Neotylenchus albulbosus	—	,, ,,	,,
Pratylenchus penetrans	Root-lesion nematode	Walnut, cherry, olive	,,
,, *vulnus*	,, ,,	Vine	,,
,, *pratensis*	Meadow eelworm	Cereals, roots, cotton, coffee, tea, tobacco	World-wide
Radopholus similis	Burrowing nematode	Spreading decline of citrus	U.S.A.
Rotylenchulus reniformis	Reniform nematode	Many crops	U.S.A., S. and W. Africa
Rotylenchus spp.	—	Banana, yam	Australia, Fiji, W. Africa
CRICONEMATIDAE			
Belonolaimus gracilis	Sting eelworm	Maize, peanut, celery, strawberry	U.S.A.
Cacopaurus pestis	—	Dieback of walnut	,,
Criconemoides spp.	—	Peach	,,
Criconema spp.	—	Pathogenicity not proved.	,,
Dolichodorus spp.	Awl nematode	Red-root of maize and celery	,,
Paratylenchus hamatus	—	Dieback of fig	,,
APHELENCHIDAE			
Aphelenchoides cocophilus	—	Red-ring of coconut	W. Indies, S. America
,, *fragariae*	Leaf eelworm	Strawberry "bunch"	Europe, U.S.A.
,, *ritsema-bosi*	,, ,,	Chrysanthemum	Europe, U.S.A., Brazil, S. Africa
,, *oryzae*	Rice nematode	White-tip of rice	U.S.A., Japan
DORYLAIMIDAE			
Trichodorus spp.	Stubby-root eelworm	Maize, bean, beet, tomato	U.S.A.
Xiphinema spp.	Dagger eelworm	Many crops	U.S.A., Brazil

The life-cycle of the root-knot nematodes (*Meloidogyne* spp.) differs in a number of important respects. There is no resistant cyst: eggs are laid into a jelly-like mass which may be extruded to the outside of the root or, under less favourable conditions, inside the root tissue. Hatching occurs when the soil is moist, independent of any root diffusate and as soon as the ova have developed, so that there may be a continuous hatching and invasion of roots, giving 10–12 generations in the year. Some of these larvae may return to the root in which they were hatched; the egg masses then become buried in a mass of proliferating tissue and are liberated only on the decay of the root. This forms the "resistant" phase of root-knot nematodes.

Some nematodes are carried on the seed. A notable example is *Aphelenchoides oryzae*, cause of "white tip" in rice, which overwinters under the hulls; it multiplies on the seedlings, producing a new generation every 15 days, spreads from plant to plant in the irrigation water, and eventually moves up the straws and invades the ears.

HOST-PARASITE RELATIONSHIPS

The effect of many eelworms on the host plant, apart from such morbid symptoms as wilting and leaf-drop, is to induce abnormalities of growth. These may take the form of complex root "knots" (*Meloidogyne* spp.) (Figure 12), galls (*Anguina* spp.) (Figure 6), grotesque malformations of leaves and stems (some *Aphelenchoides* spp.) or simple terminal swellings of the root (such ectoparasites as *Xiphinema* and *Belonolaimus* spp.). Some abnormalities are detectable only on microscopic examination of the plant.

With cyst-forming and root-knot eelworms the most typical feature of the pathology is the formation of "giant cells" around the head of the nematode. In the case of potato and beet eelworms these giant cells are syncitia formed by the dissolution of the walls of adjacent cells. There is little or no hypertrophy of individual cells, although the nuclei become enlarged, and no increase in cell division; that is to say, there is no swelling of the root.

With root-knot infections, on the other hand, hypertrophy of the cells surrounding the nematode's head and a stimulation of cell division in the pericycle cause a local swelling of the root or "knot," and the next stage is the formation of syncitia by dissolution of cell walls. The conducting system is interrupted and parenchyma around the giant cells may become differentiated into disorganized vascular tissue, as shown in the xylem-like elements immediately below the giant cell in Figure 13.

These cell changes are believed to be induced by a secretion from the oesophageal gland, loosely termed saliva, which the eelworm injects by means of its protrusible spear. This substance increases the permeability of the cell walls and finally breaks them down altogether, thus ensuring a plentiful supply of food to the parasite, which never wanders in the root once feeding has begun. This happens only in a suitable host plant.

Some species of eelworm are host-specific for one or two plant genera, for example the potato-root eelworm is specific to the genera *Solanum* (potato) and *Lycopersicon* (tomato); others, such as the beet eelworm, find suitable hosts in a number of plant families, and some of the root-knot eelworms are polyphagous to the extent of over 100 plant families. Within eelworm species from time to time strains or races are discovered which are more specific than others, and as our knowledge improves these come to be recognised as distinct species.

Plants differ in attractiveness, ease of penetration and suitability for the development of the parasite, and, when eelworm larvae reach a plant root, one of four situations can develop [17]:

1. *No larvae enter the root.* This occurs, for instance, when potatoes are grown in a soil inoculated with beet eelworm larvae, presumably because the potato-root diffusate lacks an attractant for beet eelworm or contains a repellent or masking substance.
2. *Few larvae enter and none develop.* For example when black nightshade (*Solanum nigrum*) was grown in soil inoculated with potato eelworm larvae, a few individuals were found in the roots, but these degenerated and died without increasing in size or moulting [4].
3. *Many larvae enter but few or none develop.* When roots of *Nicotiana tabacum* and *N. megalosiphon* were grown in soil inoculated with root-knot larvae, both plants were invaded to the same extent; but in *N. tabacum* the larvae developed normally and reached maturity, whereas in *N. megalosiphon* only a few reached maturity and took longer to do so [3].

   The degeneration and death of eelworms in the plant tissues may be explained by postulating the lack of a specific nutrient or the presence of a toxic substance, or a general nutritional inadequacy owing to the failure of the plant to respond as described earlier. It is

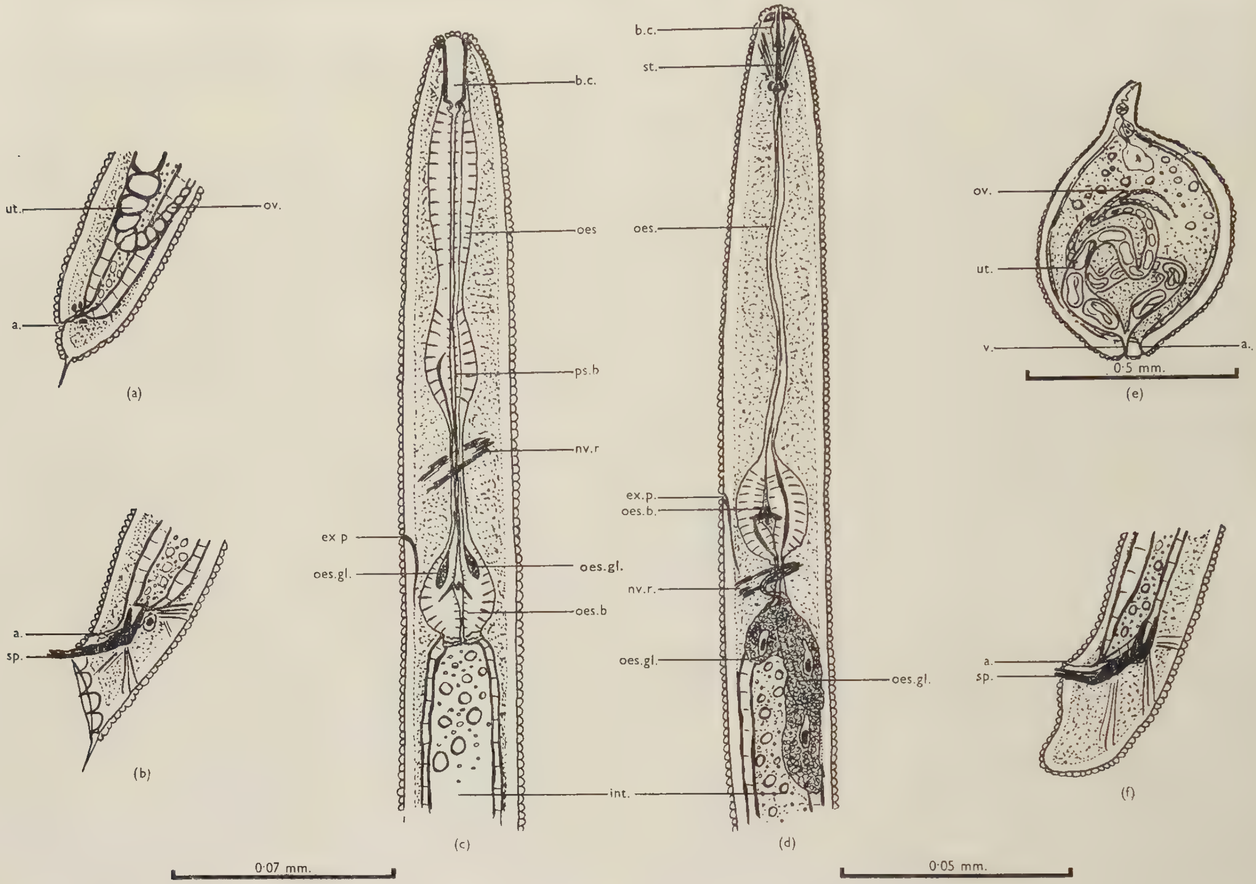

FIG. 1. Diagrams of (left) a free-living eelworm, *Rhabditis*, showing (*a*) female tail, (*b*) male tail, (*c*) adult, anterior end; (right) a plant parasite, *Heterodera*, showing (*d*) adult, anterior end, (*e*) mature female (low magnification), (*f*) male tail.

b.c., buccal cavity; st., stylet; oes., oesophagus; oes.b., oesophageal bulb; ps.b., pseudo-bulb; nv.r., nerve ring; ex.p., excretory pore; oes.gl., oesophageal glands; int., intestine; a., anus; ut., uterus; ov., ovary; sp., spicules; v. vulva.

significant that giant cells are seldom formed in unsuitable host plants and that surviving eelworms are found most often in association with the few giant cells that do occur. On the other hand, larvae entering the roots of resistant plants may cause the root tissues and sometimes the plant itself to die.

4. *Many larvae enter and many develop.* In this case the plant is a suitable host. Even within this category great variation exists in the length of time taken to complete the life cycle. When pineapple and cowpea plants (both highly suitable hosts) were inoculated with root-knot eelworm larvae and grown under identical conditions, the development of the female to the egg-laying stage took 35 days in pineapple and 19 days in cowpea [12]. (When this work was done, it was not realized that totally different figures might have been obtained using different varieties of pineapple and cowpea.) Striking differences in degree of resistance may occur not only among varieties of the same plant genus, but among varieties of the same plant species.

Several authors have suggested that resistant plants may produce chemicals which either neutralize the toxic action of the salivary secretion or are inimical to the nematodes. Such a substance might be synthesized by the aerial parts of the plant and translocated to the root, and this theory received some support when it was found that grafting a resistant scion of *Lycopersicon peruvianum* on a tomato rootstock conferred a degree of resistance on that rootstock. The same work, however, showed no change in susceptibility to *Heterodera rostochiensis* of potato roots cross-grafted with the resistant *Solanum nigrum* [10].

Nothing is known of the composition of eelworm saliva and its chemical effect on the host tissues. The use of radioactive tracers and new techniques of bioassay may make progress possible in this neglected field of research.

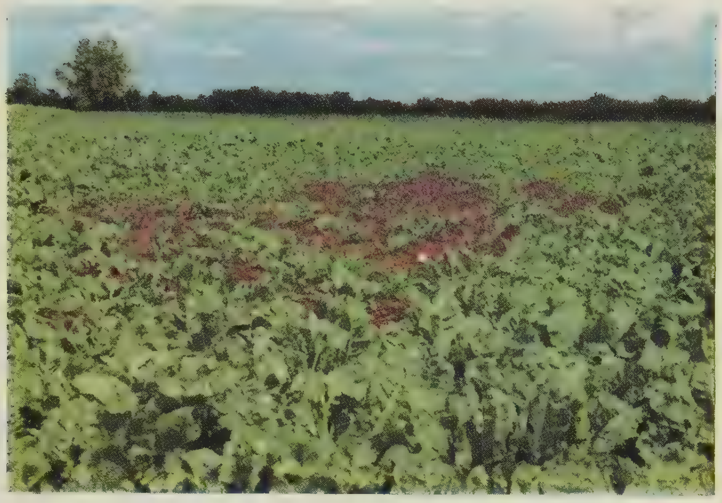

FIG. 2. Sugar beet patch infested with the root eelworm, *Heterodera schachtii*.

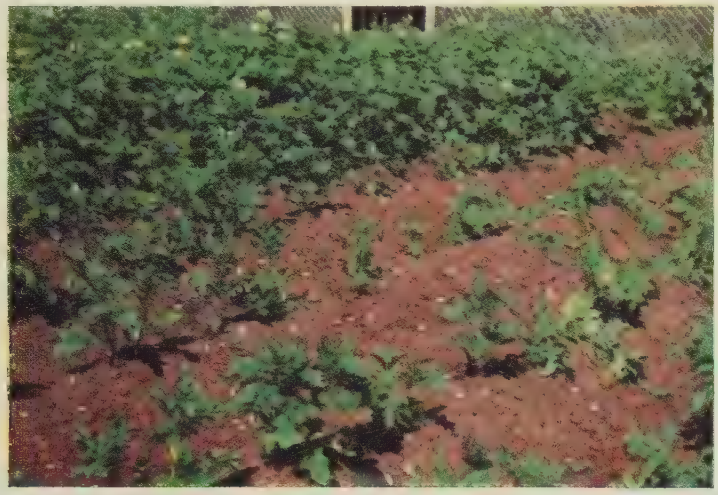

FIG. 3. Potatoes attacked by *Heterodera rostochiensis*, showing patchy nature of infestation.

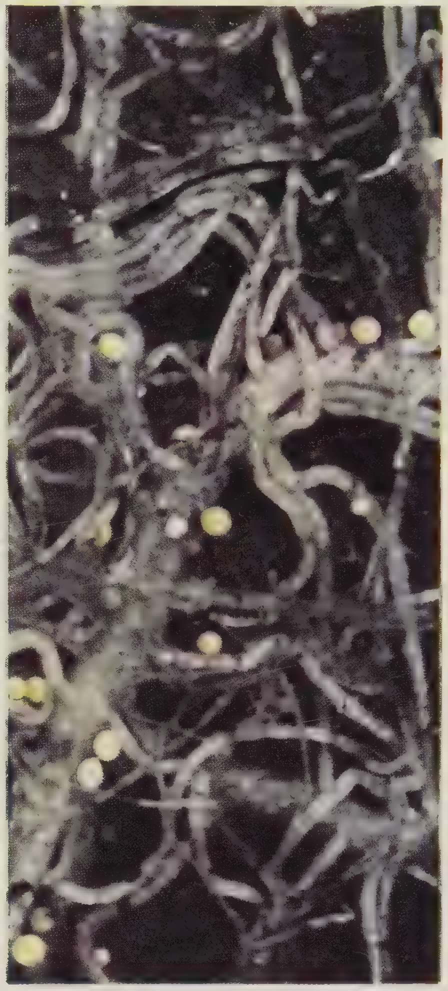

FIG. 5. Cysts of *Heterodera rostochiensis* on potato roots. (Enlarged)

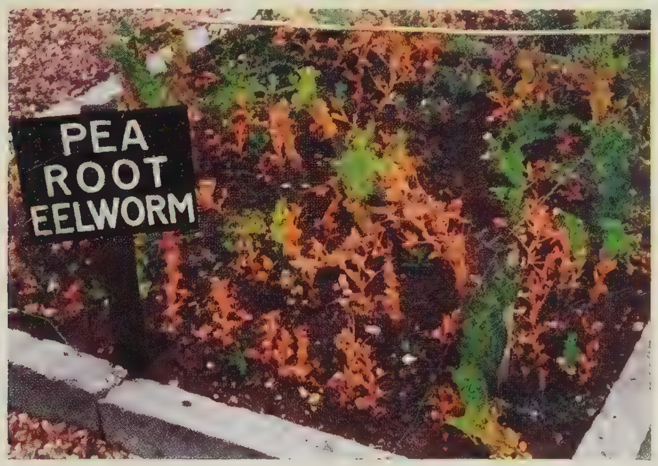

FIG. 4. Peas severely injured by the root eelworm, *Heterodera gottingiana*.

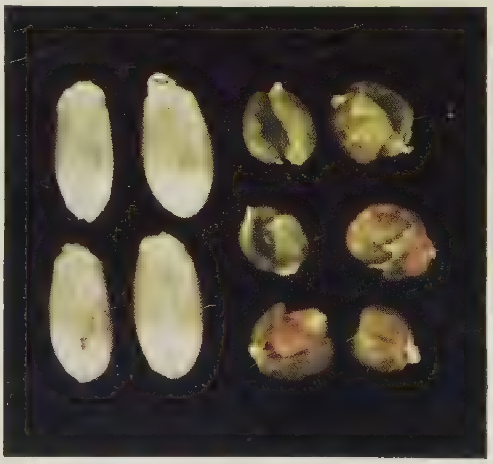

FIG. 6. Wheat seed showing (right) ear cockles caused by *Anguina tritici* and (left) healthy seed.

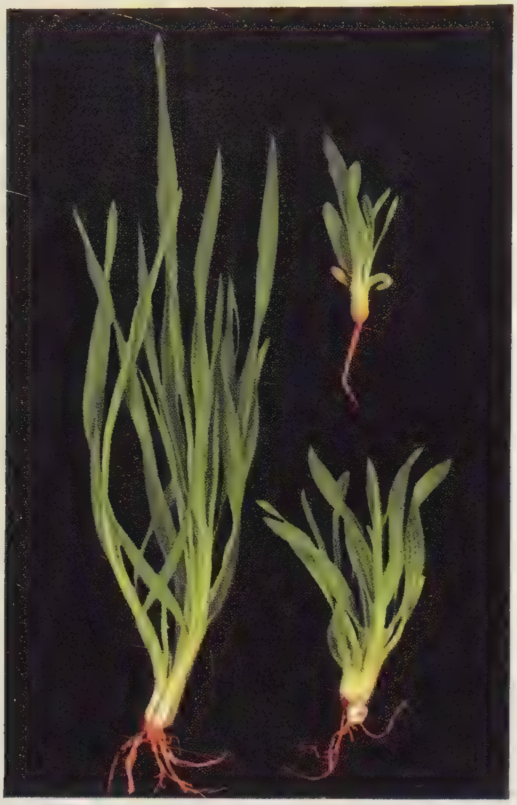

FIG. 7. Rye seedlings showing (right) symptoms of attack by *Ditylenchus dipsaci* and (left) a healthy plant.

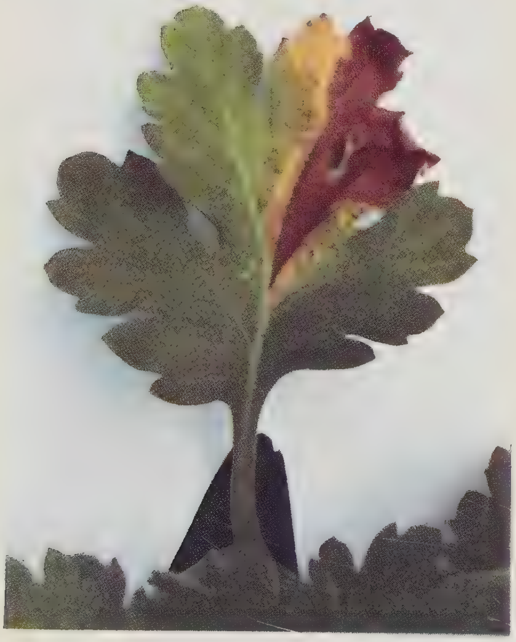

FIG. 8. Leaf symptoms of *Aphelenchoides ritzemabosi* on chrysanthemum.

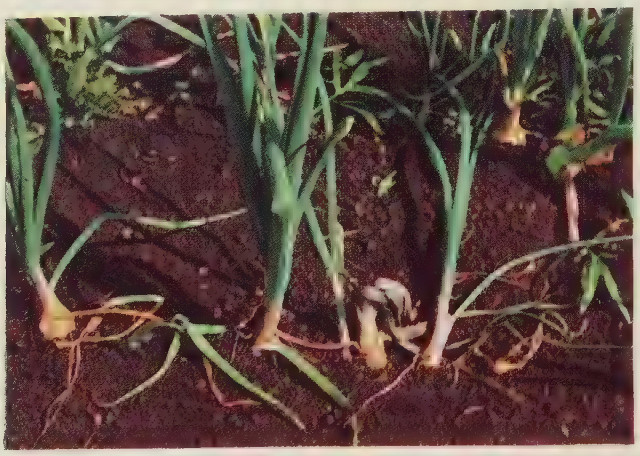

FIG. 9. Onion plants attacked by the stem eelworm, *Ditylenchus dipsaci*.

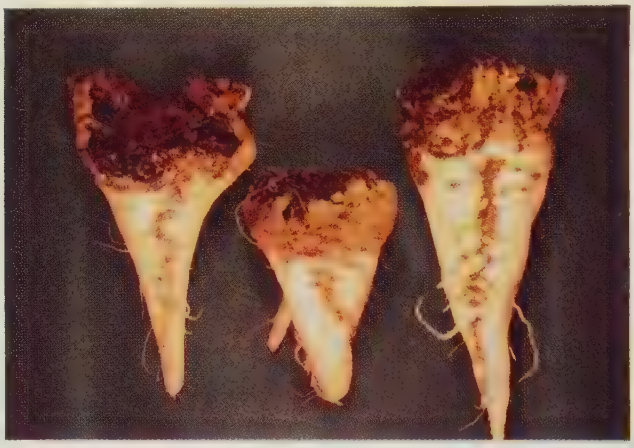

FIG. 10. Sugar beet showing crown canker caused by *Ditylenchus dipsaci*.

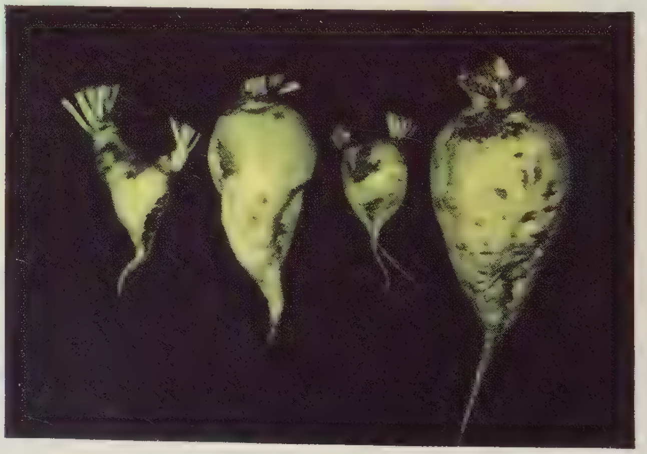

FIG. 11. Mangolds showing stunting and multiple-crown formation caused by *Ditylenchus dipsaci*.

CONTROL

Eelworm control in the field is one of the most difficult problems that face the plant pathologist. It is easy enough to kill the isolated larvae; and to meet quarantine requirements and to prevent the local spread of eelworms such transported plant material as bulbs, seeds, strawberry runners, chrysanthemum stools, citrus replants and balled nursery stock are normally and successfully disinfested by hot-water treatment or by fumigation. Leaf eelworms (e.g. *Aphelenchoides ritzema-bosi* on chrysanthemums) can also be well controlled by repeated spraying with parathion, and promising results have been obtained with such systemic materials as demeton and schradan applied either to the foliage or the soil. In the greenhouse, where the expense is justified, steam-sterilization or chemical fumigation of soil provides an economic answer to the problem of root-knot nematodes; but there is as yet no satisfactory way of destroying eelworms in the field or of protecting plants from their attack, and the cyst-forming species particularly have proved to be highly resistant to all measures so far tried against them.

Crop rotation is of limited value as a means of eelworm eradication. The less resistant species (root-knot, dagger, awl and sting nematodes) generally have a wide host range which enables them to survive on weeds. On the other hand, the cyst-forming potato-root eelworm can persist for ten years or more in the absence of a host, and although under these conditions its numbers decline each year by roughly one-half, a susceptible crop will bring about a tenfold increase in one year; ten years of a non-susceptible crop would therefore be needed to counteract the build-up in population produced by three crops of potatoes [16].

Early planting coupled with the use of fertilizers to encourage rapid growth is frequently beneficial: if the potato, for example, is able to establish a sound root system before attack by the root eelworm, a good yield may be obtained even though the roots are heavily infested.

A considerable plant-breeding programme is being carried out in Britain and in Holland with the object of producing an eelworm-resistant potato. Between 1941 and 1948 Ellenby [7] tested *Solanum tuberosum* material from the Commonwealth Potato Collection at Cambridge, and two South American species, *S. tuberosum andigenum* and *S. vernei*, were found to contain lines that were resistant to the potato-root eelworm. Further work [6, 19] has shown that their resistance is a dominant genetical factor, and plant-breeders in

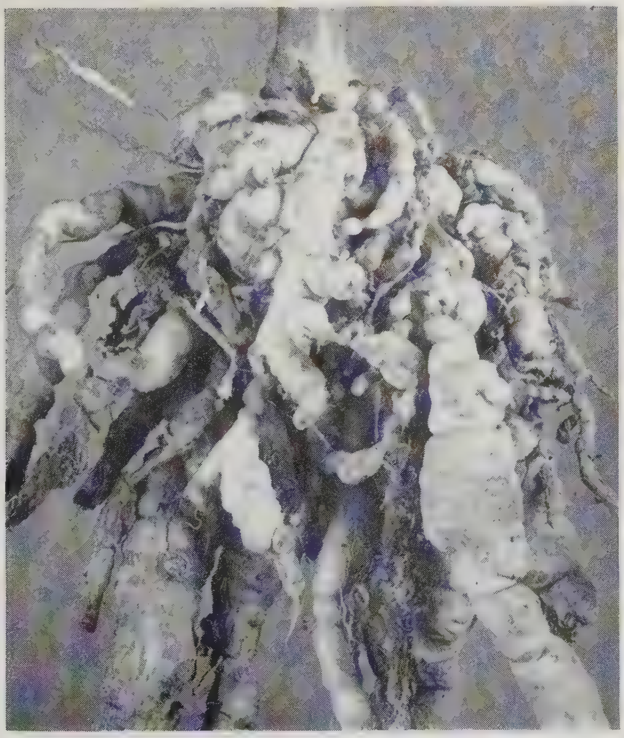
FIG. 12. Tomato root, showing severe hypertrophy caused by *Meloidogyne* spp.

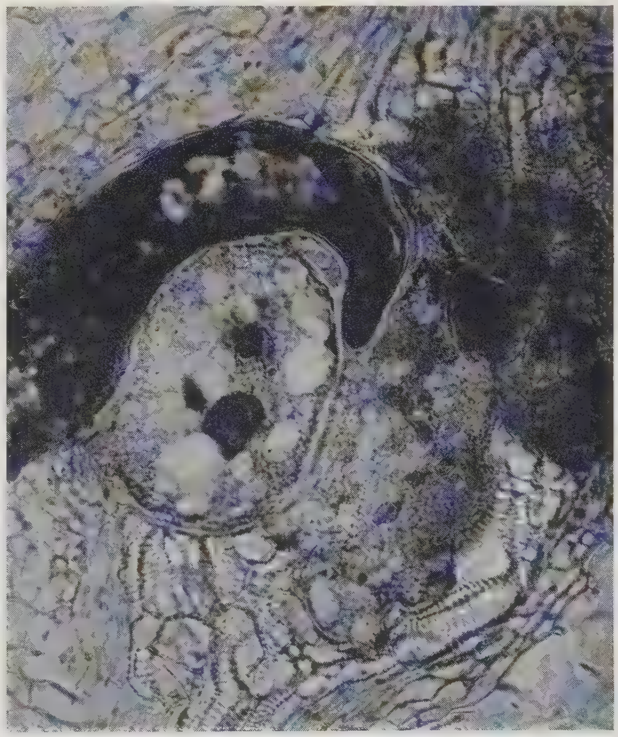
FIG. 13. L.S. of tomato root, showing larva of *Meloidogyne* sp. and associated giant cell complex.

Holland and at Cambridge are now co-operating in the work of back-crossing resistant seedlings with varieties of *S. tuberosum* to produce a commercial potato variety which is eelworm resistant. Similarly, tomato-breeding work in Hawaii over the past ten years has now produced from *Lycopersicon peruvianum* × *L. esculentum* (tomato) some selections which are both horticulturally acceptable and homozygous for root-knot resistance [11].

Biological control by artificially encouraging the rapid development of natural enemies of nematodes has been attempted by several workers. The organisms which have received most attention are the zoophagous fungi, of which over 50 species feeding on nematodes have been described; some success has been reported in pot and small-plot experiments [5, 14]. Practical drawbacks to field-scale application of this method are the massive quantities of fungus and organic matter necessary, and the fact that the fungus feeds indiscriminately on parasitic, free-living and predatory eelworms.

Various attempts have been made to control cyst-forming eelworms by inducing the cysts to hatch prematurely in the absence of host plants. Several workers have studied the root diffusate which "triggers off" hatching in cyst-forming eelworms. Although the chemical constitution of the natural "hatching factor" is not known, a substance (anhydrotetronic acid) has been synthesized which is as effective as root diffusate in inducing encysted larvae of the potato-root eelworm to hatch [1]; unfortunately it was not possible to produce this chemical in quantity cheaply enough for it to be used in practice.

Recent work has shown that an attractive diffusate may be produced by a plant that is not a suitable host; in Holland a cruciferous weed, *Hesperis matronalis*, was found to be highly attractive to *Heterodera schachtii*, while not permitting the development of the parasite [15]. This at first sight would appear to be a promising means of control. The drawbacks are, firstly, that the weed is not a strong grower and it has not been possible so far to get adequate cover of a field; secondly, even with a strong growing plant a fairly high proportion of the cysts are not reached by the root systems, so that several years' cropping with a commercially valueless crop would be necessary.

The search for an effective chemical treatment of the soil has produced several compounds lethal enough to eelworms to protect the crop in its early stages and thereby to ensure an economic return in the year of application, but the eelworm population builds up again rapidly. The difficulty of mixing a substance intimately with the top 6–9 in. of soil on a field scale has concentrated attention on chemicals of a fumigant nature; these are usually toxic to plants and must be applied some weeks before the land is to be sown or planted to allow the residues time to disperse. Examples of such compounds widely used at present are methyl bromide, ethylene dibromide, chloropicrin, chlorobromopropene, dibromochloropropane, and dichloropropene-dichloropropane mixture. Their use is restricted by cost (£15 to £20 per acre) to seedbeds and crops of high cash value, such as tobacco, cotton, fruit, vegetables and glasshouse crops, and the problem of controlling soil eelworms in the field is still far from being solved.

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REFERENCES

[1] Calam, C. T., Todd, A. R. and Waring, W. S. (1949). *Biochem. J.*, **45**, 520–4.

[2] Chitwood, B. and Oteifa, B. (1952). *Annu. Rev. Microbiol.*, **6**, 151–84.

[3] Christie, J. R. (1946). *Phytopathology*, **36**, 340–52.

[4] Doncaster, C. C. (1953). *J. Helminth.*, **27**, 1–8.

[5] Duddington, C. L. (1956). *The Friendly Fungi*, pp. 161–2. Faber and Faber, London.

[6] Ellenby, C. (1952). *Nature, Lond.*, **170**, 1016.

[7] Ellenby, C. (1954). *Euphytica*, **3**, 195–202.

[8] Fenwick, D. W. (1956). "Preliminary Investigations into Red-ring Disease of Coconuts." Trinidad and Tobago Agricultural Society, Monthly General Meeting, June 1956. Port of Spain.

[9] Fielding, M. H. (1951). *Proc. helminth. Soc. Wash.*, **18**, 110–12.

[10] Forster, A. R. (1956). *Nematologica*, **1**, 283–9.

[11] Gilbert, J. C. and McGuire, D. C. (1956). *Proc. Amer. Soc. hort. Sci.*, **68**, 437–42.

[12] Godfrey, G. H. and Oliviera, J. M. (1932). *Phytopathology*, **22**, 325–48.

[13] Goodey, T. (1933). *Plant Parasitic Nematodes and the Diseases they Cause.* Methuen & Co., London.

[14] Linford, M. P. and Yap, F. (1939). *Phytopathology*, **29**, 596–609.

[15] Ouden, H. Den (1956). *Nematologica*, **1**, 138–44.

[16] Peters, B. G. (1950). *Farming*, **4**, 338–41.

[17] Sasser, J. (1954). *Md. Agr. Expt. Sta., Bull. A*-77 (*Tech.*), 1–30.

[18] Steiner, G. (1951). *Calif. Citrogr.*, **36**, 396–7.

[19] Toxopeus, H. J. and Huijsman, C. A. (1952). *Nature, Lond.*, **170**, 1016.

ECOLOGICAL ASPECTS OF WEED CONTROL

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This discussion on weed ecology emphasizes that the weed flora of a region may undergo striking changes over long periods. Nevertheless weed populations possess important properties of stability which make it unlikely that the use of herbicides will lead to major weed problems from previously minor, but herbicide-resistant, weeds. Susceptible species may develop resistant strains, and action must be taken to meet this danger.

When a herbicide is applied to weeds in a crop or in grassland the immediate consequences appear simple and advantageous to the farmer; yet the elimination or depression of one or more constituent species upsets a natural balance, involving changes in the abundance of every organism connected with the one against which the herbicide is directed, and some of the long-term consequences may be undesirable.

It is the purpose of this article to consider the effects that weed control may have on the balance of plant and animal populations and the types of problems which these may present. It is hoped that this discussion will enable some of these problems to be forestalled or met appropriately when they occur and that it will increase awareness of the dangers which may arise from indiscriminate use of chemical weed control.

ORIGIN OF WEED POPULATIONS

Weeds are the "camp followers" of crops and represent undesirables which have escaped from normal communities into a new and remunerative niche. Where man has replaced natural vegetation by a controlled system of cropping or management, the species previously adapted to the area disappear and others which find the environment favourable to them invade the site.

Some weeds of cultivated land appear to have spread out from communities of natural vegetation. The creeping buttercup (*Ranunculus repens*), ribwort plantain (*Plantago lanceolata*), sheep's sorrel (*Rumex acetosella*) and ragwort (*Senecio jacobaea*) are characteristic inhabitants of natural communities on sand dunes, and the daisy (*Bellis perennis*), coltsfoot (*Tussilago farfara*) and mouse-ear chickweed (*Cerastium vulgatum*) appear in the natural open communities of high mountain slopes [31]. Such species are now more conspicuous in the new niches than in the original habitats. These weeds are perennials and are common weeds of grassland.

In contrast, many weeds of arable land are not native to Britain, and the list of such species has grown rapidly since Roman times. Godwin [20] lists 50 weed species which made their first appearance in Britain in the Post-Glacial period. Of these the most interesting are white mustard (*Sinapis alba*), the corn marigold (*Chrysanthemum segetum*), the cornflower (*Centaurea cyanus*) and the wild oat (*Avena fatua*). These introduced weeds are mainly annuals, but a few additions to the perennial grassland flora appeared in this way, e.g. the bulbous buttercup (*Ranunculus bulbosus*) and the ox-eye daisy (*Chrysanthemum leucanthemum*).

In Britain the relatively long established weed populations contain species that were once used for food but are now regarded as useless and undesirable. Seeds of white goosefoot (*Chenopodium album*), black bindweed (*Polygonum convolvulus*), pale persicaria (*Polygonum lapathifolium*) and corn spurrey (*Spergula arvensis*) as well as tubers of onion couch (*Arrhenatherum tuberosum*) have been identified in the stomach contents of Iron Age man [20].

Recent Introductions

Augmentation of the weed flora continues. Chance transport of the seed of alien species in ballast or as contaminants of agricultural seed or imported foodstuffs, and the spread of plants deliberately introduced for garden cultivation, provide a continuous supply of new species, which may find themselves well adapted to man-made habitats.

Brenan [8] found 91 adventive species growing in the neighbourhood of Southampton Docks, many of which were typical weeds in grain fields in the eastern Mediterranean region; the waste land of the ports provides a sorting ground for new species which, if they survive to set seed, may then be transported over the British Isles. Lousley

[29] has reviewed the recent influx of aliens into the British flora. A regular practice of chemical weed destruction in the immediate neighbourhood of ports and docks is probably the greatest safeguard against the spread of new and potentially dangerous weeds.

Classic cases of introduced weeds making rapid spread are Buxbaum's speedwell (*Veronica persica*), which was first recorded in Britain in 1825 and is now common in cultivated land [14], and hoary pepperwort (*Cardaria draba*), which was introduced about 150 years ago and is now well distributed throughout England and Wales, is spreading rapidly and becoming a very dangerous weed. It is characteristic of introduced species to make rapid initial spread and for the population then to diminish and reach a fairly steady size well below that of the epidemic outbreaks. This tendency is well illustrated by the behaviour of Canadian pondweed (*Elodea canadense*), which was introduced in about 1836 into Ireland, and in 1842 to England, and spread rapidly until it blocked many waterways; it is now widespread but seldom abundant. A new wild oat (*Avena ludoviciana*) was recorded in 1926 at Abingdon in Berkshire and is now distributed to a distance of 80 miles around Oxford—a good example of spread from an "infection" centre [42]. It is also a matter of concern that garden plants may escape and become weeds of agricultural land—this has occurred recently with species of *Oxalis* in south and west England.

Such new weeds can be most effectively controlled in the early stages of spread, and it is important for farmers and advisers to be trained to recognize weeds so that new arrivals may be spotted and eliminated before they have had a chance to become established. Where new species of weeds are becoming established, localized crop destruction and even "quarantine" measures may be a price worth paying to keep a dangerous weed suppressed.

Especially serious weed problems have arisen in New Zealand and Australia associated with the bulk introduction of European crops and their contaminants. Thomson [41] gives a classic account of the additions to the New Zealand flora, in which introduced species, such as ragwort, provide serious weed problems. In Australia ragwort invasion has in some cases been checked by the total destruction of pioneer plants, but where the weed was not recognized for several years elimination proved very costly or impossible [19].

ADAPTATIONS TO ENVIRONMENT

A weed flora may suffer occasional losses, quite apart from deliberate eradication. Ragwort exhibits extraordinary fluctuations [25], and there is some indication that these changes are cyclic. Other changes have been caused by alterations in farming practice. The corn cockle (*Agrostemma githago*), which has been an important cornfield weed until recently, has declined in importance owing to better seed cleaning and weed control and the diminished cultivation of rye [20]. Larkspur (*Delphinium ajacis*) and pheasant's eye (*Adonis annua*), both introduced species which flourished as weeds, have now almost disappeared. The cornflower, which again is associated with rye cultivation, has been a characteristic cornfield weed but is now rarer and rather local in Britain, though still a common weed in northern Europe.

Changes within Species

Changes in the weed flora have also been brought about by changes in the weed species themselves. Salisbury (cited by Huxley [27]) has recorded that the introduction of reaping machines eliminated the taller strains of spreading hedge parsley (*Caucalis* (*Torilis*) *arvensis*) and fools' parsley (*Aethusa cynapium*) and that dwarf forms now characterize arable land.

New species have also arisen by hybridization followed by polyploidy—for example the hemp nettle (*Galeopsis tetrahit*) is believed to have originated in this way—and it is certain that the facilities offered in arable land for the cohabitation of closely related species provide the ideal opportunity for this to occur. A particularly dangerous situation arises where a weed and a crop are closely related biologically and where natural selection operates to increase this similarity to the point where weed and crop are harvested together and remain almost impossible to separate. This situation arises with wild oats in cereals and with charlock in cultivated mustard, and indeed genetic contamination of the crop may occur in such circumstances. Another example is provided by Russian sub-species of *Camelina sativa*, which are adapted in respect of growth form, time of capsule dehiscence, and reaction to threshing and winnowing to the particular form of flax or linseed which they infest as weeds [40].

The effects of weed control measures must therefore be considered against a background of weed populations which alter from year to year as a result of new introductions and the slow elimination of species by changes in the environment.

Effects of Crop Rotation

The most obvious and fundamental changes in weed populations are brought about by crop rotation, which is designed in part as a weed control measure. Under systems of monoculture weeds that can compete successfully with the crop may reach epidemic proportions.

Some indications of the extent to which different crops are associated with different weeds is shown by the relative frequency of weed seeds in grain samples tested at the National Institute of Agricultural Botany. These values must be interpreted with care, because (*a*) they exclude weeds that are eliminated in normal seed cleaning; (*b*) they represent the percentage of samples contaminated, not the intensity of contamination; and (*c*) they are obtained from samples sent for testing, which gives a biased estimate.

Nevertheless the data indicate a strong tendency for certain crops to be more commonly contaminated by one weed than another. Autumn cultivation allows autumn-germinating species to grow up with the crop, whereas spring cultivation penalizes these weeds and favours species with characteristic spring germination. Under rotational cultivation, therefore, the weed pattern is continuously changing.

The natural vegetation of an area must by its nature be able to survive all the recurring hazards to which it is exposed, and in the same way the very act of crop rotation has selected out and favoured the weed species that are important on arable land today. In particular, species capable of long-continued dormancy (natural or enforced by burial) can survive a crop rotation so long as a proportion of the seeds remains viable until a compatible crop and cultivation allow a population to set seed again. This is very well illustrated by the behaviour of the cornfield poppies [30].

STABILITY OF WEED POPULATIONS

Paradoxically, because weed populations are exposed to continually changing environments, there is a remarkable tendency to overall stability. This has some relevance to weed control, for the weeds which are now common are innately buffered against elimination. In this sense the task of chemical weed control has been made more difficult by the past practice of rotational weed control.

It is striking that the relative order of frequency of weed seeds in the grain samples examined at the N.I.A.B. has remained almost the same each year from 1928 to 1952 despite such profound changes in agricultural practice as fluctuations in grain acreage, expansion of ley farming, the introduction of combine harvesters, changed varieties, and the widespread use of herbicides. Brenchley and Warrington [9] comment that the component species of a weed flora are essentially the same for both continuous autumn-sown wheat and spring-sown barley, but their relative abundance is markedly changed by the different crop cultivations and the greater competitive ability of the autumn-sown wheat.

FREQUENCY OF OCCURRENCE OF WEED SEEDS IN OFFICIAL SEED TESTING STATION CEREAL SAMPLES (N.I.A.B. DATA FROM BROAD [10])

Data for 1951–2

Wheat	Barley	Oats	Rye
Galium aparine 8·4%	*Polygonum convolvulus* 16·9%	*Polygonum convolvulus* 11·4%	*Polygonum convulvolus* 15·4%
Polygonum convolvulus 5·9%	*Galium aparine* 12·2%	*Galium aparine* 11·5%	*Vicia hirsuta* 11·4%
Polygonum aviculare 2·5%	*Avena fatua* 7·2%	*Rumex crispus* 9·1%	*Polygonum aviculare* 7·7%
Rumex crispus 2·4%	*Atriplex patula* 4·7%	*Polygonum persicaria* 4·8%	*Galium aparine* 5·7%
Atriplex patula 2·1%	*Brassica* spp. 4·4%	*Atriplex patula* 4·7%	*Polygonum persicaria* 5·4%
Avena fatua 1·6%	*Polygonum aviculare* 3·5%	*Polygonum aviculare* 4·3%	*Brassica* spp. 4·0%

Percentage values indicate proportion of samples containing each weed.

Influence of Dormancy

Most of the common weeds of agricultural land have the ability to remain dormant, and, although the proportions of species in a field vary greatly from year to year as they are buffeted by changes in practice, the buried seeds prevent the elimination or marked reduction of any of the species.

In a study of buried weed seeds in a 50-year-old pasture Chippindale and Milton [13] found nearly all the viable seed in the top 6 in. of soil, though there were marked differences between species. For example, most of the viable seed occurred with *Bellis perennis* in the surface 2 in., with *Rumex obtusifolius* in the third inch and with *Ranunculus repens* in the fourth; *Juncus bufonius*, however, showed a minor peak at a depth of 2–3 in. and a major one at 5–7 in. Where such an accumulation of dormant weed seed has built up, chemical sprays may exert a negligible lasting effect on the infestation, even if practised for several consecutive years.

This tendency for a population to develop inertia as a result of continued selection—termed "homoeostasis" by geneticists and animal ecologists [4, 28]—is shown markedly in grassland, both with sown species and weeds. Although the balance of species in a new ley can quickly be changed by alterations in management, the longer a pasture has been established the more difficult it is to change the balance of species within it by management.

In arable land where dormant seeds give stability to the weed population, even in face of repeated herbicide application, there is an obvious need for methods by which dormancy may be broken.

Where dormancy is enforced by impermeability of the seed coat, as in the wild oat, germination can be induced only by decomposition of this barrier, which presumably occurs in nature, or by deliberate puncturing. Sometimes dormancy can be broken chemically, and Åberg [3] has reported that 2,4-D or 2,4,5-T stimulated the germination of cleavers, corn spurrey (*Spergula arvensis*) and pale persicaria (*Polygonum lapathifolium*). Brown [11] has shown that parasitic weeds, such as *Striga* and broomrape (*Orobanche* spp.), are stimulated to germinate by a substance or substances in root exudations from potential hosts.

These are isolated examples from an almost unexplored field, and great advances in weed control would obviously follow the discovery of chemical means of promoting the germination of dormant weed seeds and so exposing them to the action of weedkillers.

Other Stabilizing Influences

Other factors contribute to the stability of weed populations in areas that have been sprayed. Weeds are continuously being spread to cultivated land from hedgerows and waste places, and crop seed carries with it small and sometimes large contaminations of seeds of weeds which had been successful in the parent crop and so are likely to succeed in the daughter crop. A 1% contamination (by weight) of a cereal sown at 1·5 cwt. per acre will involve sowing on each square yard about 40 seeds of cleavers or 20 of black bindweed or wild radish [26]. Chemical weed control would make little lasting impression on land receiving such contaminated seed.

The reproductive capacity of weeds is often enormously high: the average seed output per plant is about 1000 for groundsel (*Senecio vulgaris*), 6000 for common sow-thistle (*Sonchus oleraceus*), 17,000 for cornfield poppy (*Papaver rhoeas*) and 23,000 for spiny sow-thistle (*Sonchus asper*) [35]. Ragwort may yield up to 174,000 seeds per plant [12]. This implies a fantastic rate of increase, but it is rarely realized. The phenomenal increase of *Veronica persica*, already cited, is an example of a species which must have approached this potential rate; but when such a weed colonizes a site the spread is nearly exponential at the start, then slows down until the death rate is balanced by the establishment of new individuals and the population remains constant.

It follows that the controlling factors operate more severely when numbers are high than when they are low, and that prolific seeding of individuals in an established community is the major contributing cause of high mortality of progeny. This is of the greatest importance for understanding the dynamics of weed populations and the changes which follow. It is therefore easier to control a rapidly expanding than a stabilized population.

One way in which this "density-dependent mortality" acts in practice is that destruction of seedlings by pre-emergence spraying permits later germinating seeds of the same species to establish themselves successfully where they would previously have been suppressed. Of course, the treatment would have removed the early weeds that compete dangerously with the crop, but those which escaped the herbicide by later germination, when its potency had been reduced, would set seed and provide the continuum. Control in this way need not result in fewer adult weeds in the following year.

The density of adult plants may actually *prevent* germination of seeds of the same species. This is seen when grassland infested with buttercups (*Ranunculus bulbosus*) is sprayed with 2:2-dichloropropionic acid (dalapon). Doses high enough to kill grasses and buttercups give bare patches on which buttercup seedlings emerge in large numbers; unsprayed plots show no such seedling populations. In such a case the density of buttercups is rapidly restored by the removal of some inhibition previously exerted by the adult population on the buried seeds.

Although a prolific seeder can colonize new areas far more rapidly than a species with few seeds per plant, the maximal population size achieved at equilibrium is independent of seed output. Darwin realized this and commented (*Origin of Species*) "the fulmar petrel lays but one egg, yet it is believed to be the most numerous bird in the world."

The reduction in size of a weed population by any means creates conditions under which, on return of the old environment, the population will equilibrate to the same size. The rate at which a weed will re-invade depends on the homoeostatic factors of the particular population, reproductive capacity of the species and the extent of reduction achieved. If therefore weed control measures are to have any degree of permanence they must either be repeated frequently or management must change the environment to make re-invasion impossible.

In the above context there is no contradiction between the proponents of weed control by good management and of weed control by spraying [16, 17]. Especially is this true in grassland, where a high degree of weed control can be achieved by management, but only slowly because the homoeostatic processes operate strongly in a community of vegetatively reproducing plants. Herbicide treatment, on the other hand, may give quick elimination of the weed followed by swift re-invasion. To control weeds by herbicides and to prevent re-invasion by management is the most sensible procedure.

BIOTIC RELATIONSHIPS

Weeds, like all plants, occupy intermediate positions in food chains: they require food materials for their own growth and are themselves required by various organisms as food. The size of a weed population and the vigour of its members may therefore be limited by two sets of natural factors: (*a*) the amount of available nutrients, water and light, for which the crop and other weed species may be competing; and (*b*) the attacks of herbivorous animals, insects and plant pathogens which in one way or another destroy the leaves, seeds or roots. These organisms may be controlled in turn by the amount of the food plant available or by the attacks of parasites, which may again be controlled by hyper-parasites or by a limited supply of food material.

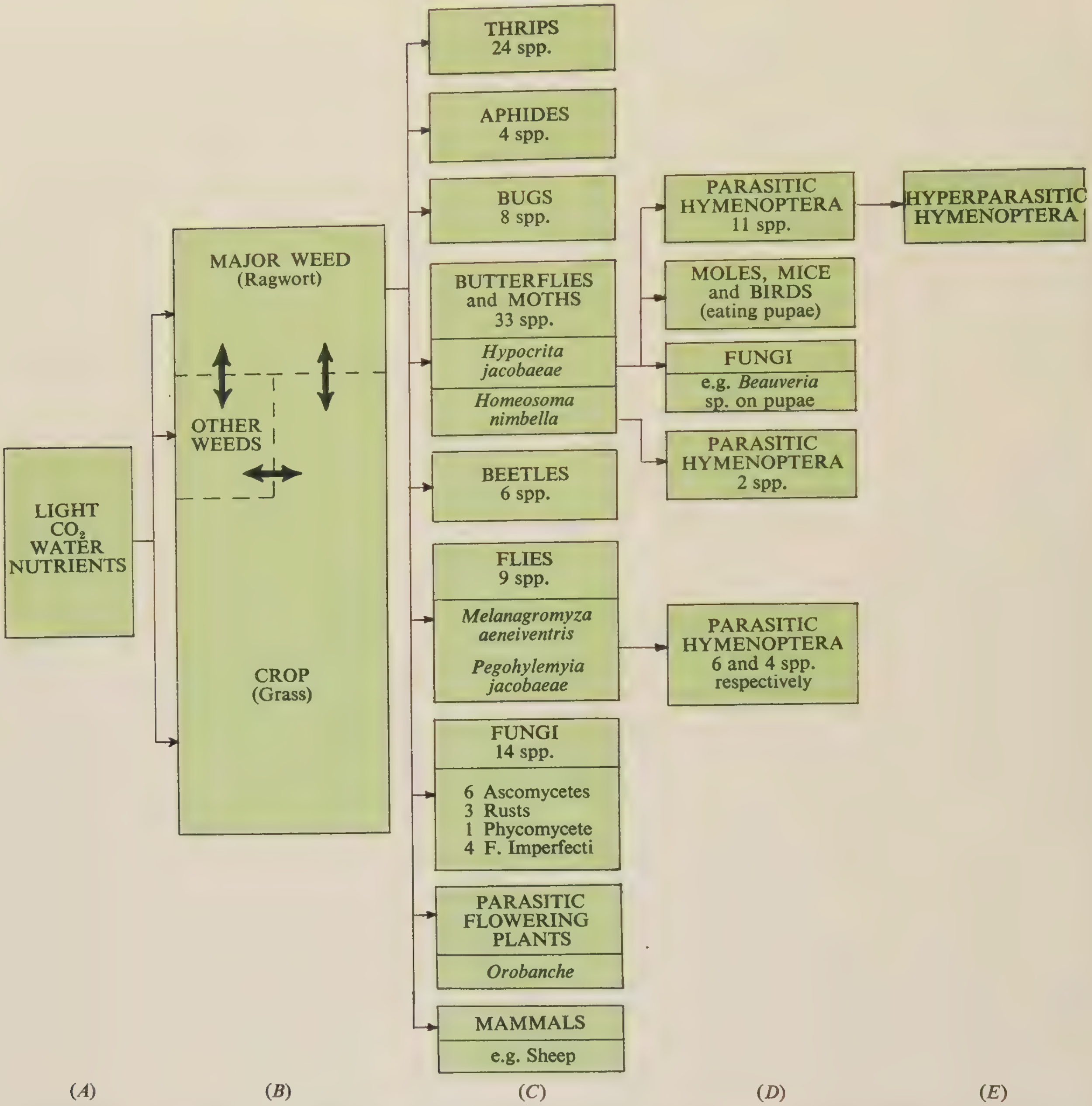
This situation and the complex inter-relations it creates between crop and weed are exemplified in the diagram (p. 202), which shows for ragwort what is probably the most comprehensive food chain that has been made for any weed, though many links are missing.

The growth requirements of ragwort are, of course, the same as those of other plants in the sward, and the absolute quantities available to it are influenced by the efficiency with which the crop and other weeds can monopolize them. After the temporary elimination of the weed from a pasture its re-invasion can be checked by good management and fertilizer treatment designed to promote the growth of clovers and grasses, so that these may compete effectively with new ragwort seedlings and shade them out.

Competition between weeds and crop may be very severe—if it were not, weeds would be little nuisance. Blackman and Templeman [6] have shown that in a cornfield the competition between charlock (*Sinapsis arvensis*) and the crop is largely for nitrogen, while in the case of the taller wild radish (*Raphanus raphanistrum*) in dense infestations competition for light is more important. The demands of a weed for water may also be heavy, and Derscheid [18] showed that white goosefoot may transpire 800 lb. of water during the production of 1 lb. of dry matter compared with 500–600 lb. of water transpired by wheat, barley and oats for an equal dry matter gain.

Predators and Prey

We know very little of the organisms that directly attack weeds and next to nothing of their parasites, although these may be of fundamental importance in the natural control of weed populations. The interactions between predator and prey are often unpredictable because the number of factors concerned is so large. Ripper [34] has discussed the oscillations that occur in insect populations consequent on the application of insecticides: in some instances partial destruction of a pest leaves a migratory population of its



Diagrammatic food chain of a weed exemplified by ragwort, *Senecio jacobaea*. The columns denote: (*A*) plant growth requirements; (*B*) weed-crop relationships; (*C*) organisms attacking ragwort; (*D*) parasites and predators; and (*E*) their hyper-parasites. The numbers of species are those so far recorded in the U.K., but the list is far from complete, particularly for parasites and hyper-parasites. The arrows in (*B*) indicate the changes in composition of a weedy crop (ragwort-infested pasture, in this instance) which may follow changes induced in the food chain: expansion or contraction of the ragwort population is relative to that of the crop or other weeds. Herbicidal treatment of ragwort may be followed by re-invasion of other weeds or expansion of the crop, or both, and all the organisms in the food chain are affected.

predators which may clear up the remnants of the pest; in others, elimination of the pest is followed by starvation of its natural predators, and the pest population then expands to new epidemic proportions because its natural controlling agent has been removed.

In the case of ragwort, the cinnabar moth (*Hypocrita jacobaeae*) seems to be a most important controlling factor, for in most years the caterpillars strip the foliage and even the inflorescences over large areas. Cameron [12] showed that in Britain the population of cinnabar moths is limited by many larval parasites and that these in turn are controlled by hyper-parasites. The pupae are destroyed by moles, mice, birds and fungi: losses of pupae through predation have been estimated at more than 60%, and from fungi 16–20%. A major reduction in the ragwort population by chemical weed control will upset the biological balance and set in motion oscillations of all the interlinked organisms in the chain, which may lead to resurgences of the weed population.

Another interesting link in the food chain of a weed was demonstrated by Colquhoun [15], who found that the staple diet of woodpigeons in June was buttercup seeds. But excepting the buttercup and ragwort, which have been studied in considerable detail [24, 25], our knowledge of biotic relationships for almost all other weeds is deplorably scanty.

Deliberate attempts have been made to control weeds by biological means. The cinnabar moth was introduced into New Zealand after being freed from its parasites, in the hope that it would then control ragwort; unfortunately this attempt failed, because local predators quickly adapted themselves to take the cinnabar caterpillars as an alternative food source. Other attempts have been more successful, notably the control in Australia of the dwarf prickly pears (*Opuntia inermis* and *O. stricta*) by the introduced insect *Cactoblastis cactorum*. There has also been striking control of *Clidemia hirta* by an introduced species of thrips (*Liothrips urichi*) in Fiji [37–39].

EFFECTS OF HERBICIDES

Various changes in the composition of vegetation may follow the control or elimination of a weed, as indicated in the food chain diagram. Although weed populations tend to be stable, lasting changes may result from "relentless pressure" by some external agency, such as continued application of herbicides. This, however, will seldom occur, because the farmer is unlikely to continue to spray when the density of the weed falls below what he considers damaging to the crop; rather will he switch his attention to other weeds, often using a different weedkiller.

Fate of Resistant Species

It has been suggested [1, 7, 32] that the control of a weed by a chemical treatment may lead to the expansion of populations of weeds resistant to that chemical. In California continued spraying of roadsides with mineral oils killed out the original vegetation, only for it to be replaced by oil-resistant umbelliferous weeds. Claims are often made that changes of this kind in the weed flora are already occurring in Great Britain, and in particular that cleavers and fumitory (*Fumaria officinale*) have become more troublesome in corn crops after spraying with 2,4-D or MCPA. These claims are usually verbal and difficult to substantiate. There is no indication from the N.I.A.B. data of an increase in cleavers up to 1952. It is possible that reported increases of this weed are due to breakage of dormancy by 2,4-D as recorded by Åberg [3] rather than to the removal of competition from other weeds.

Balme [5] has described a four-year study on the weed population of some roadside verges which were sprayed annually with 2,4-D. She found that susceptible species (mainly dicotyledons) disappeared in the first year and that there was a significant increase in grass cover; but the grass/dicotyledon ratio increased only slightly in succeeding years owing to the survival of resistant weeds. In general, highly susceptible species were killed by a single treatment, and species that were not reduced by this showed no ill effects after four years' treatment. On some sprayed plots certain weeds showed a significant *increase*, probably the result of reduced competition from nettles (*Urtica dioica*), which originally formed dense stands.

Although Balme found significant changes in that part of the flora which was resistant to the herbicide, including increases in some species which could be attributed to the removal of competitors, she emphasized that "in this type of community, the natural changes in floristic composition from year to year were as significant as the changes imposed by spraying." Balme also commented on another verge experiment that "the experiment clearly demonstrated the impermanence of chemical control of perennial weeds in an unstable habitat of this type."

In theory, increases in weeds resistant to herbicides should occur only if they had been in competition with the susceptible species removed by spraying; but the main competitor of a weed is usually the crop, and removal of the weed will then be followed by increased growth of the crop rather than of other weeds present. Moreover, any weed which manages to creep into a niche left by the elimination of another will usually be a less severe competitor with the crop—if it had been a more effective competitor it would have been a major weed before spraying.

Pfeiffer *et al.* [32] make the point that the genetic ability of the crop to expand into spaces left by the elimination of weeds must be important in permitting maximum yield returns from the application of herbicides.

Changes in the composition of a weed flora involving the spread of a previously minor weed seem therefore unlikely to follow the repeated use of a herbicide, and the situation is particularly unlikely to occur where herbicides of unrelated nature (e.g. 2,4-D and DNC) are rotated. Of course, the removal of a major weed by spraying may make a farmer aware of the existence of subsidiary species which had been there all the time but now show up as "major" weeds in an otherwise clean crop. This may account for the view that certain weeds are increasing as a result of spraying.

Resistant Mutants

Of greater importance is the fact that weeds susceptible to a particular herbicide may become resistant as a result of the continuous selection of resistant mutants. Already it has been reported [21] that *Erechtites hieracifolia*, which had been effectively controlled by 2,4-D in Hawaiian sugar cane plantations, has developed resistance to this herbicide. Where these strains have appeared, strong doses of contact herbicides are now needed to kill the weed. Abel [1] has noted that increasing doses of 2,4-D were required to control creeping thistle (*Cirsium arvense*).

The emergence of new strains of old weeds poses more serious problems than the replacement of one species by an existing but less important weed species. A resistant strain of weed which has been selected by the application of a herbicide would ordinarily possess most of the biological characteristics that had made it a target worth spraying. Harper [24] has discussed the conditions under which a selective act of weed control may lead to the evolution of resistant strains. Clearly, where every treated weed is killed no selection is possible; but any treatment that allows a few individuals to escape damage, by virtue of their heritably greater tolerance of the chemical, provides the ideal conditions for selection to occur. Hence herbicide applications aimed at control but not elimination are especially dangerous (unless they prevent flowering or seed set).

Even where complete kill of growing weeds is practicable, a selective advantage is given to later germinating variants, which may spread in the population. The length of the dormancy period is sometimes under genetical control—McNaughton and Harper (unpublished data) have found that this is true for the cornfield poppies—and Vavilov has shown that the evolution of strains with different germination behaviour can be quickly achieved by selection. These late-germinating strains would be less dangerous competitors to the crop than early-germinating strains; indeed, a later-germinating weed may be suppressed by the crop. A more serious danger is that morphological or biochemical properties of a mutant may confer resistance to herbicides without affecting the essential "weediness" of the species.

Selection occurs most rapidly in large populations of species that seed profusely and possess a large reserve of inherent variation; the outbreeding annual weeds, such as the poppies, are examples. On the other hand, vegetatively reproducing or inbreeding species and those with low reproductive capacity or small population size respond slowly to natural selection. Hence weeds of grassland and the perennial weeds of arable land are less likely to provide problems than the cornfield annuals.

Once again the buffering action of buried viable weed seeds provides an important resistance to the evolution of new weed strains. A large population of unselected members of the species delays the establishment of new genetic forms where outbreeding is common.

Preventing the Evolution of Resistant Weeds

The following recommendations were made by Harper [24] for preventing the evolution of weeds resistant to herbicides:

1. Where possible, two independently acting herbicides should be used in combination. The chance of two mutants arising in the same organism to confer resistance to such a combination is remote. Rotation of herbicides will also help, but not so effectively as their use in combination.
2. Quick-acting herbicides should be preferred to those with slow action, particularly if the plants can produce some viable seed while dying.
3. Total kill should be the aim when herbicides are applied—doses which only "set back" the weed are undesirable. Synergism may be a way of increasing the percentage kill by herbicides; synergistic action has recently been reported between 2-methyl-6-chlorophenoxyacetic acid (the 6-isomer) and 2-methyl-4-chlorophenoxyacetic acid [33].

4. A search should be made for herbicides lacking mutagenic properties. Unrau [43, 44] has shown that 2,4-D induces chromosome breakage; such a property would increase the range of variation from which resistant forms may be selected.
5. Weed populations on waste ground provide an important genetic buffer against the evolution of new forms of weed; hence these reserves of "normality" should be conserved so far as is consistent with good agricultural practice.

CONCLUSION

Throughout this article stress has been laid on the stability of weed populations, but even the most conservative populations must be shifted in character by relentless pressure; repeated application of one herbicide to one area is such a pressure, and the consequences may be serious. Many of the problems discussed are unlikely to arise where unrelated herbicides are used in rotation or, better still, in conjunction. There is a real need for a continued increase in the number of herbicides available, particularly of unrelated types which are likely to have independent action; a wide spectrum of herbicides offers the best possibility of mastering the weed.

It is also to be hoped that advances in the chemists' approach to weed problems may be paralleled by advances in ecological studies of common weeds in view of the undesirable long-term effects that might develop through removing a weed.

REFERENCES

[1] Abel, A. L. (1954). *Proc. 2nd Brit. Weed Control Conf.* (Harrogate), 249–53.

[2] Åberg, E. (1956). *Plant Protection Conference* 1956, pp. 148–57. Butterworths Scientific Publications, London.

[3] Åberg, G. (1956). *Proc. 3rd Brit. Weed Control Conf.* (Blackpool), 141–64.

[4] Allee, W. C., Emerson, A. E., Park, O., Park, T. and Schmidt, K. P. (1949). *Principles of Animal Ecology.* Philadelphia.

[5] Balme, O. E. (1956). *Proc. 3rd Brit. Weed Control Conf.* (Blackpool), 771–8.

[6] Blackman, G. E. and Templeman, W. G. (1938). *J. agric. Sci.*, **28**, 247–71.

[7] Blackman, G. E. (1950). *Selective Toxicity and the Development of Selective Weedkillers.* Roy. Soc. Arts, London.

[8] Brenan, J. P. M. (1947). *Rep. bot. (Soc.) Exch. Cl. Manchr.*, **13**, 106–12.

[9] Brenchley, W. E. and Warrington, K. (1933). *J. Ecol.*, **21**, 103–27.

[10] Broad, P. D. (1952). *J. nat. Inst. agric. Bot.*, **6**, 275–86.

[11] Brown, R. (1946). *Nature, Lond.*, **157**, 64–9.

[12] Cameron, E. (1935). *J. Ecol.*, **23**, 265–322.

[13] Chippindale, H. G. and Milton, W. E. J. (1934). *J. Ecol.*, **22**, 508–31.

[14] Clapham, A. R., Tutin, T. G. and Warburg, E. W. (1952). *Flora of the British Isles.* C.U.P., Cambridge.

[15] Colquhoun, M. K. (1951). *Rep. agric. Res. Coun.*, **10**, 1–69.

[16] Davies, G. Maxwell (1953). *Proc. 1st Brit. Weed Control Conf.* (Margate), 158–65.

[17] Davies, W. (1953). *Proc. 1st Brit. Weed Control Conf.* (Margate), 155–8.

[18] Derscheid, L. A. (1952). *Proc. Joint Meeting 9th Cent. Weed Cont. Conf. and 6th West. Canad. Weed Control Conf.*, 93–5.

[19] Gardner, C. A. (1948). *J. Dep. Agric. W. Aust.*, **25**, 124–8.

[20] Godwin, H. (1956). *The History of the British Flora.* Cambridge.

[21] Hanson, N. S. (1956). *Down to Earth*, **12**, (2), 2–5.

[22] Harper, J. L. and Sagar, G. R. (1953). *Proc. 1st Brit. Weed Control Conf.* (Margate), 256–63.

[23] Harper, J. L. (1956). *Proc. 3rd Brit. Weed Control Conf.* (Blackpool), 179–88.

[24] Harper, J. L. (1957). *Herbage Abstracts.* (In press.)

[25] Harper, J. L. and Wood, W. A. (1957). *J. Ecol.* **45**, 617–37.

[26] Horne, F. R. (1953). *Proc. 1st Brit. Weed Control Conf.* (Margate), 372–99.

[27] Huxley, J. (1942). *Evolution. The Modern Synthesis.* London.

[28] Lerner, I. M. (1954). *Genetic Homoeostasis.* Edinburgh.

[29] Lousley, J. E. (1953). *The Changing Flora of Britain.* Arbroath.

[30] McNaughton, I. H. (1956). *Proc. 3rd Brit. Weed Control Conf.* (Blackpool), 189–96.

[31] Matthews, J. R. (1955). *Origin and Distribution of the British Flora.* London.

[32] Pfeiffer, R. and Zeller, A. (1953). *Proc. 1st Brit. Weed Control Conf.* (Margate), 70–3.

[33] Poignant, P. and Richard, R. (1954). *C. R. Acad. Sci.*, Paris, **239**, 1660–2.

[34] Ripper, W. E. (1956). *Ann. Rev. Ent.*, **1**, 403–38.

[35] Salisbury, E. J. (1942). *The Reproductive Capacity of Plants.* London.

[36] Salisbury, E. J. (1954). *Proc. 2nd Brit. Weed Control Conf.* (Harrogate), 289–300.

[37] Simmonds, H. W. (1932). *Agric. J. Fiji*, **5**, (1), 18–20.

[38] Simmonds, H. W. (1933). *Agric. J. Fiji*, **6**, (2), 32–3.

[39] Simmonds, H. W. (1937). *Agric. J. Fiji*, **8**, (2), 37–9.

[40] Stebbins, G. L. (1950). *Variation and Evolution in Plants.* Columbia, N.Y.

[41] Thomson, G. M. (1922). *The Naturalisation of Animals and Plants in New Zealand.* Cambridge.

[42] Thurston, J. M. (1953). *Proc. 1st Brit. Weed Control Conf.* (Margate), 240–8.

[43] Unrau, J. (1953). *Rep. Canad. Seed Gro. Ass.*, 1952–3, 25–8.

[44] Unrau, J. (1954). *Rep. Canad. Seed Gro. Ass.*, 1953–4.

MASTITIS. AN APPRAISAL OF ITS PRESENT-DAY IMPORTANCE

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Progress in the control of mastitis in dairy cows has not been so great as is popularly believed. Although mastitis caused by Streptococcus agalactiae *has been much reduced in British herds by the general use of antibiotics, the disease is still prevalent because sub-clinical cases are ignored. Other forms of mastitis which do not respond to therapy have assumed a greater role, and we shall have to deal with these increasingly in future.*

It may appear paradoxical that, at a time when dairy farmers in Great Britain are over-producing, it should be considered so essential to prevent the loss of milk caused by mastitis; but it is, in fact, quite logical. The profit-margin for milk production is narrowing, and we cannot afford the additional loss due to udder damage. It is quite possible that we have reached saturation point so far as raw milk consumption is concerned, and our aim must now be to produce more milk more economically from fewer herds and channel the farms that are less suited to dairying into other forms of agriculture, such as beef production, where there is still a shortage.

GENERAL CONSIDERATIONS

Loss from Mastitis

In a recent article Laing and Malcolm [7] have estimated that the loss due to mastitis from reduction in milk yield and the cost of stock replacement is £19 million per annum in the United Kingdom. This was based on the assumption that one-third of our dairy cattle have mastitis and that each affected cow loses 12% of its potential milk yield. It was estimated that 124,000 animals have to be bought each year to take the place of animals culled from the herds because of mastitis. These figures, however, were not derived from a random sample of our herds: an undisclosed proportion of the herds was examined because a mastitis problem existed and the remainder were sent in by farmers anxious to determine the mastitis state of their herds, an anxiety hard to understand unless there was cause for worry.

In the U.S.A. the loss due to bovine mastitis was recently estimated [5] at 226 million dollars, or one-third of the total cost of all cattle diseases, while in New York State alone the annual loss from mastitis was given as 30 million dollars. This figure is derived, however, from an alleged incidence of 25% of cows infected with *Str. agalactiae*, an incidence that is considered to be much higher than we believe to exist in the British Isles today. The methods of estimating the loss due to mastitis must be, by the widespread nature of the disease and its varying aetiology, inaccurate, but no one will deny that the loss is considerable.

It is the purpose of this article to discuss what progress in controlling mastitis has been made and to point out how, as one problem has been solved, new problems, even more difficult of solution, have appeared.

Assessment of Incidence

In the British Isles the true incidence of mastitis has never been properly established at any period, and so we shall never know what progress we have made in reducing the overall incidence. The reasons for this are that the type of mastitis and its extent differ from district to district, depending on the system of farming, size of the herd, geographical position, and perhaps even climatic conditions. We know that summer mastitis is most common in the north and west of this country, but why? And why is *Str. agalactiae* still relatively common in herds in Dorset yet almost unknown in Norfolk? Thus a survey in one area cannot be applied to the country as a whole.

Another difficulty in determining the incidence of the disease is variation in the estimates of different individuals as to what constitutes mastitis. This does not apply only to farmers and cowmen: even practising veterinary surgeons and research workers have divergent views as to what is meant by mastitis. A comprehensive definition of mastitis which is widely used is "Any alteration of the udder or its product, milk."

This definition is open to criticism. It would include those cases where clots appear in the milk at oestrum, or as a result of the injection of an oestrogen; but this physiological change in milk secretion is *not* mastitis. It would exclude those numerous cases where the udder and milk are apparently normal and microscopical examination of the milk reveals an excessively high number of cells, indicative of the presence of a sub-clinical mastitis. Many research workers have considered the recovery of pathogenic organisms from the milk to be sufficient to diagnose mastitis in the cow, but it is only when this infection proceeds to invasion that mastitis ensues. Mastitis is present only when there are indications of an inflammatory process either visible to the naked eye by the manifestations of heat, pain and swelling or, in the case of sub-clinical mastitis, from the presence of abnormally high numbers of bacteria in the milk as revealed by a direct count of the milk or by indirect methods, such as the Whiteside test.

MASTITIS DUE TO *Str. agalactiae*

Britain has been responsible for much valuable work on mastitis. The foundations of this were laid by Drs. Stableforth, Edwards and Minett [10] in their excellent fundamental research on the bacteriology of mastitis carried out in the years before the war. Their work could not be built on, however, as they lacked the "mortar" of a method of treatment that was really efficient in removing bacteria from infected udders. Nevertheless, by eliminating infected cows they established a herd that was free from *Str. agalactiae* and maintained it so for a number of years. They thus demonstrated what could be achieved if a satisfactory treatment ever became available. It is significant that their main interest was in streptococcal infection; staphylococcal mastitis was not then of major importance, apparently, at least so far as cows were concerned.

Eradication by Antibiotics

The advent of antibiotics, spearheaded by penicillin, at last presented the weapons with which to attack mastitis seriously. At that time, immediately after the war, *Str. agalactiae* was the major pathogen in mastitis. Various surveys have been carried out to determine the relative incidence of the different mastitis pathogens in clinical cases, and one nation-wide sample showed that over 40% of cases in 1942 were due to *Str. agalactiae*. A later survey by Hughes [6] of all the cases treated in one large practice showed that, even in 1953, 20% of cases were still due to this organism.

In 1945, when penicillin first became available to us, the first objective was to achieve by treatment of infected cows what Stableforth and his colleagues had done by elimination, namely the eradication of *Str. agalactiae*. It was fortunate that this *was* the organism most worthy of attention as it has a restricted habitat, being largely confined to the udder for a living, and it is capable of eradication because there are few reservoirs of infection outside the udder. Furthermore, *Str. agalactiae* is sensitive to penicillin and has never been shown to develop resistance to it *in vivo*.

As a result of a long series of experiments, initiated by Lancaster and Stuart [8] in the laboratory herd at Weybridge and subsequently in over 600 herds in the field, a system of herd treatment for the eradication of *Str. agalactiae* was laid down. It is believed that this system will repay its cost in a very short time. Briefly, it consists of bacteriological examination of all cows and treatment of those found to be infected with *Str. agalactiae*. Repeat tests are carried out to ensure that treatment has been effective. During this period strict hygienic precautions are essential to prevent spread of infection, since the disease is carried from cow to cow by the milkers' hands, the udder cloths and the teat clusters.

Results of Treatment

This form of mastitis is not the problem today that it was in the pre-penicillin era. Last year the incidence of *Str. agalactiae* in 4000 clinical cases examined at Weybridge was only 4%, but it would be wrong to think that this reduction from 40% means that we are only suffering one-tenth of the damage; much of the damage is sub-clinical, and only by the bacteriological examination of milk samples is the true extent of the infection revealed.

Although it is not possible at the moment to examine every herd bacteriologically, or even a suitable random sample, many of the herds examined at Weybridge, because they have a mastitis problem, are still heavily infected with *Str. agalactiae*. It would appear that, because penicillin provides the immediate answer for the clinical cases which arise periodically, the sub-clinical cases are ignored. Only when clinical cases are numerous are farmers provoked into action, and many must be feeding cows milking well below their potential yield and unaware of it since the cause is not obvious.

It is unfortunately true that no figures exist which give accurately the loss of milk from a cow that has become infected with *Str. agalactiae*. Experiments have been carried out by infecting one quarter of the udder and comparing its milk yield with that of the corresponding healthy quarter, but compensating hypertrophy in this disease-free quarter tended to exaggerate the apparent loss, while reducing the actual loss, and a true figure could not be assessed.

To establish the true loss of milk caused by *Str. agalactiae* mastitis it would be necessary to maintain a herd of identical twins, exposing one of each pair to infection and keeping the other under identical conditions as a control. This sounds simple; but other forms of mastitis and other diseases also affect the milk yield and are not so easy to control, making an experiment of this nature almost impossible to carry out. In any case the cost of such an experiment would be prohibitive, and data from the field indicate that to free badly infected herds from *Str. agalactiae* is very much worth while.

Figures derived from field sources are open to criticism because so many factors affect milk yield, some advantageously and some adversely; but if a large enough sample of herds is chosen in which the only common factor is the removal of *Str. agalactiae* then the other factors affecting the milk yield will tend to neutralize one another and we can attach some importance to the data. Thus, in comparing twenty-five herds involving 1000 cows that had been treated in 1949 to eradicate *Str. agalactiae*, it was shown that the average milk yield had risen from 1949 to 1953 by 140 gallons. During this time the National Herd average had risen by 70 gallons (much of it owing to improved mastitis treatment) and, since the only factor common to these herds was the removal of *Str. agalactiae*, it could safely be assumed that the eradication of this organism was responsible for an increase in the milk yield of 70 gallons a year on an average, or approximately 10%.

As has already been stated, many herds today are still heavily infected, but lack of facilities in the Veterinary Investigation Laboratories has made it difficult to tackle this problem with the necessary vigour—and vigour *is* necessary to eradicate *Str. agalactiae*. It is a contagious disease and, if only one cow is left infected, the organism can quickly re-establish itself in udders which, although freed from infection, are very susceptible to re-infection.

However, this is a mastitis problem to which there is a remedy, and only in exceptional cases nowadays do we fail to eradicate the infection within a few months. Unfortunately the same is not true of other forms of mastitis. With the fall in the incidence of mastitis caused by *Str. agalactiae*, other organisms have become more important—an importance that is more than relative to the decline of *Str. agalactiae*—and with these we shall have increasingly to deal as the years go by.

STAPHYLOCOCCAL MASTITIS

The most notable increase of all has occurred in the case of mastitis associated with *Staphylococcus pyogenes*: from a mere 8%, which was its incidence in 1946, it has jumped to over 25%. It must be borne in mind, however, that there is a high degree of selection in those samples from clinical cases of mastitis which are sent for bacteriological examination. Because they respond so well to antibiotic therapy many cases of streptococcal masititis are never sampled, but even in the years since penicillin has been available, when such a consideration would be effective, there has been a steady increase in the incidence of staphylococcal mastitis. The examination of milk samples from herds having a mastitis problem also shows that staphylococci are the most frequently occurring infections.

The theory has been postulated that the removal of *Str. agalactiae* has allowed staphylococcal infection to take advantage of the freedom from competition for a living inside cows' udders. But attempts to substantiate this have failed to show that, when *Str. agalactiae* was removed from a herd, the quarters originally infected became more readily infected with *Staph. pyogenes* than quarters that had previously been healthy.

It would be unwise to assume that because two things occur simultaneously they must be related to one another. Of the twenty-five herds freed from *Str. agalactiae* in 1949 only four showed an increase in staphylococcal infection in 1953. To pursue this point further, two herds each of fifty cows which had a high incidence of both forms of mastitis were chosen. All streptococcal infections were treated, but the staphylococcal infections were left alone. Both herds were examined monthly for two years, and in neither herd did the amount of staphylococcal infection increase after the removal of *Str. agalactiae*. To complete the picture, milk yields in both herds rose by over 100 gallons a cow, but a change in management which occurred at the same time must have played a part in this increase.

Effects of Machine Milking on Incidence

Nevertheless staphylococcal mastitis has increased, and if it is not due to the clearance of *Str. agalactiae* then some other explanation must be found. A possible reason is that the shortage and high cost of agricultural labour in the years after the war forced more and more farmers to change from hand to machine milking, and there is evidence to suggest that the increase in staphylococcal mastitis is confined to machine-milked herds. A number of machine-milked and hand-milked herds in which mastitis was present were compared at Weybridge to determine the relative frequency of staphylococcal infection. Bacteriological examination of milk samples sent revealed that in the machine-milked herds the problem was one of staphylococci alone or of a mixture of staphylococci and various streptococci, whereas in the hand-milked herds staphylococci were rare and the prevailing organism was *Str. agalactiae*.

One large hand-milked herd about to adopt machine milking was examined bacteriologically for three months before and after the change of method, and a significant rise could be seen in the incidence of staphylococcal infection from the time the machine was introduced.

This then is a possible explanation of the increase in staphylococcal mastitis; but the seemingly obvious remedy of a return to hand-milking is not feasible, although many small herds that are machine-milked today could be milked more economically by hand. The most extreme example the writer has encountered was a "herd" of two cows milked by machine and using two units! No herd of ten cows or less can be milked as economically by machine as by hand.

Resistance to Antibiotics

Another reason for the increase in staphylococcal infection might be its resistance to treatment, notably to penicillin. When penicillin was first introduced it was reported that only 2% of cases were resistant to its action, whereas a more recent survey from 500 clinical cases of mastitis showed that 40% were now resistant. This is not a development of resistance but a change of population from sensitive to resistant strains. In some herds all strains are now penicillin-resistant; in others, despite prolonged therapy, all or nearly all the strains are still sensitive.

Perhaps the biggest shock we at Weybridge had in the treatment of mastitis was our realization that the final answer to infection other than *Str. agalactiae* was not to be found in the antibiotic tube. This is notably true of *Staph. pyogenes*, which, unlike *Str. agalactiae*, is not confined to the udder for a living and is found in other parts of the cow, on the milkers' hands and in their throats, and can even multiply on the intact skin.

Despite this fact, attempts have been made to eradicate staphylococci from infected herds. Stuart [11] did maintain the Weybridge experimental herd free from *Staph. pyogenes* for a period of eighteen weeks when he discontinued the experiment, and Blackburn [3] at the Hannah Dairy Research Institute had similar results; but attempts to reproduce these results in the field have been unsuccessful. In one herd which was treated and had the infection removed from all but eleven out of 200 quarters the infection rate assumed its pre-treatment level of 160 quarters within six weeks.

Vaccination

Faced with this inability to eradicate staphylococci, two other methods of approach have been tried. At Weybridge we examined the possibility of protecting the cow by vaccination. Vaccination of cows against mastitis was tried many years ago by many different workers, without general accord as to its efficiency in controlling the disease. It is perhaps significant that, where workers were wise enough to run controls with the vaccinated animals, no benefit could be demonstrated.

More recently Pattison and his co-workers [4] at Compton have published a series of papers on the immunology of *Str. agalactiae* mastitis and, although they were unfortunate in not obtaining a very significant protection when vaccinating cows, it is possible that out of their work will emerge a useful method of attacking forms of mastitis that do not respond to therapeutic measures. High hopes should not be encouraged, however, as the udder is a breeding-ground for a wide variety of organisms, and it would be a *very* polyvalent vaccine that would be capable of protecting the cows against even the relatively common mastitis organisms, far less the infrequent types which, with the passage of time, might become much more prevalent.

Reducing Udder Injury

Since vaccination and treatment with antibiotics are not yet the answer to the herd problem of staphylococcal mastitis (although clinical cases must be treated), the only avenue left to explore is the management of the cows. Granted that a cow is susceptible to mastitis and that an organism is capable of producing it, it will depend on the level of management how difficult or easy it is for the organism to damage the udder.

Although many aspects of management have a bearing on mastitis, e.g. feeding, housing and bedding, it is the use, or rather the misuse, of the milking machine which seems to be responsible for most herd problems of staphylococcal mastitis. The most usual fault is slow milking. It is appreciated that cows vary greatly in their individual speeds of milking, but a good cowman using a bucket-plant should average ten cows per unit per hour. In many herds a mastitis problem has been solved largely by the adoption of a quick milking routine. The improvement is presumably due to reduction of the injury which is alleged to be caused by improper machine milking, yet this traumatic mastitis is very difficult to reproduce under experimental conditions, possibly because of variations in the susceptibility of cows and in pathogenicity of the organisms.

So far as the milking machine itself is concerned there is evidence to suggest that teat-liner design and height of vacuum may influence the amount of mastitis in a herd, and it is hoped to carry out larger trials in commercial herds to determine what factors are most likely to affect the incidence of mastitis.

OTHER FORMS OF MASTITIS

Mastitis in Dry Cows

Treatment with antibiotics has made no difference whatsoever to the well-established case of summer mastitis. This is not because the organisms responsible, notably *Corynebacterium pyogenes*, are resistant to antibiotics, but because the pathology of the disease is of such a nature that restoration of normal function is hopeless except in an occasional case.

Some progress, however, has been made. Long-acting antibiotics injected into the udder as the cow goes dry have been shown to be effective prophylactically. Protection is of a very high order, and in districts where the disease is known to occur it is a wise plan to treat all cows with antibiotic as they are dried off, especially during the summer months when the disease is most prevalent.

Loss from summer mastitis has also been reduced by running the dry stock with the milking herd. In this way it is possible to handle the udders twice a day and to detect a case of mastitis in the early stages. If treated at this time, before the extensive necrotic damage has occurred, a complete cure is often obtained.

Attempts to contain this disease by immunological methods have not been conspicuously successful, although reports of the disappearance of the disease from susceptible herds following the use of a *C. pyogenes* toxoid are often heard. Unfortunately, no control animals (or an insufficient number) have been kept, and the spasmodic occurrence of the disease makes it impossible to attach much importance to such uncontrolled experiments. In large field trials at Weybridge, where adequate controls have been kept, no advantage in the use of such a toxoid could be demonstrated.

The old theory that the fly was the means of carrying the disease to the cow has regained its popularity following experiments in Germany, Denmark and in this country [1, 2, 9]; but the provision of an adequate seal for the teats or the production of a fly-repellent sufficiently long-acting and cheap enough to be economical in use is still awaited.

Much work remains to be done on this form of mastitis, which is a serious problem in many parts of the country. Its variable occurrence from year to year, district to district, and even farm to farm makes the job of running a controlled experiment to obtain additional information extremely difficult. It would appear that the Achilles' heel of this disease is the fly and that our efforts should be centred on control or even eradication of the insect, though cases of summer mastitis do occur in winter-time and in the absence of flies.

Miscellaneous Infections

In addition to *Staph. pyogenes*, *Str. dysgalactiae* and *Str. uberis* are frequently recovered from herds with traumatic mastitis, and the fact that they are not decreasing, as *Str. agalactiae* has done, argues that antibiotic resistance is not the reason for the increase in staphylococcal infection, since both these streptococci are sensitive to penicillin.

These two streptococci are at least as ubiquitous as the staphylococci and the same difficulty is experienced in their eradication by treatment. In one herd which was apparently freed of *Str. dysgalactiae* for two years the infection returned, although no new animals had been brought on to the farm. It has been noted that where this organism is responsible for a number of acute cases of mastitis in a herd there is usually a serious fault in the milking technique. Why this should be so is not known.

Mention must be made of the more uncommon infections which are beginning to appear in milk samples sent in for examination at Weybridge and other laboratories in this country. Some of these are man-made, and once the danger has been pointed out, the numbers of these infections have dwindled spectacularly. This is true of both the yeast-like fungi and the rapidly growing acid-fasts, such as *Mycobacterium smegmatis*, which were quite frequent at one period but are seldom met nowadays because it is now appreciated that antibiotics are not omnipotent and care must be taken to avoid introducing an infection into the udder along with an antibiotic powerless to control it.

More important than these infections, which have had their moments of brief notoriety, are the steadily increasing numbers of cases of mastitis caused by Gram-negative organisms, notably *Escherichia coli*, *Pseudomonas pyocyanea* and species of *Klebsiella*. Such infections have been common in other countries for years, and although only one case of mastitis due to *Ps. pyocyanea* was diagnosed at Weybridge in the five years 1946–51 over 30 were found in 1956 alone.

The explanation for this increase is not yet apparent. It may be that as we demand more milk from our cows we are lowering the resistance of the udder, so that organisms not normally pathogenic can establish themselves. The relative absence of mastitis in the beef-breeds seems to support this theory. There is some evidence to suggest that a trigger mechanism is necessary before those unnatural pathogens can invade the udder. In herds where *Klebsiella* was recovered from the hyperacute cases of mastitis it was discovered that a serious fault had developed in the milking machine, and the mastitis outbreaks subsided immediately the faults were corrected.

CONCLUSION

It would be wrong to suggest that we have not made some progress in mastitis control, but it has been upward progress on the "Down" escalator. As one problem has been solved others have appeared, and the most that we have been able to do is to maintain our position.

The question whether mastitis is as prevalent today as pre-war remains unanswered. Mastitis workers are naturally at variance with each other in discussing this, for in the absence of surveys giving accurate and comprehensive information of the pre-war incidence we have no means of finding out. Nor can we rely on the opinions of veterinary surgeons in private practice. They see much more mastitis today, but they see it because they can cure it. In the days before sulphanilamide and the antibiotics veterinary surgeons were not called to cases of mastitis unless these were really acute, and the treatment administered was usually empirical and of doubtful value.

It is true that there is less mastitis due to *Str. agalactiae*, although this organism is still, in the writer's opinion, infecting more cows than is popularly believed. There has been a reduction in the number of acute cases of mastitis thanks to the prompt use of the more efficient treatments now available. On the other hand, the amount of subclinical mastitis appears to be increasing, and this has been linked with the increased use of the milking machine. To what extent this affects the milk yield is not known; it is probably considerable. In the light of our present knowledge, eradication methods can only be applied to *Str. agalactiae*, the other infections being best contained by principles of sound herd management.

The fear that the bacteria causing clinical mastitis will become resistant to antibiotics does not seem to be a real one: more strains of staphylococci resistant to penicillin are being recovered, but there is little evidence that this is true of the other antibiotics as yet.

The udder is a very vulnerable gland, and it is understandable that there must be some mastitis. When one considers how by our incessant demands the gland has become hypertrophied to yield as much as ten times its natural amount of secretion and is exposed to traumatic damage and the risk of infection twice a day, it is amazing how little mastitis our cows do have.

REFERENCES

[1] Aehnelt, E. (1955). *Dtsch. Tierärztl. Wschr.*, **62**, 493.

[2] Bahr, L. (1955). *Dansk Maanedskr. Dyrlaeg.*, **63**, 365.

[3] Blackburn, P. D. Private communication.

[4] Bracewell, C. D. and Pattison, I. H. (1957). *J. Comp. Path.* (In press.)

[5] Hodges, H. G. (1956). *Vet. Science News.*, Fall 1956.

[6] Hughes, D. L. (1954). *Vet. Rec.*, **16**, 235.

[7] Laing, C. M. and Malcolm, J. F. (1956). *Vet. Rec.*, **68**, 447.

[8] Lancaster, J. F. and Stuart, P. (1949). *J. Comp. Path.*, **59**, 19.

[9] Parish, W. E. and Stuart, P. Private communication.

[10] Stableforth, A. W., Edwards, S. J. and Minett, F. C. (1935). *J. Comp. Path.*, **48**, 300.

[11] Stuart, P. Private communication.

BOOK REVIEWS

Statistical Methods for Agricultural Workers. V. G. Panse and P. V. Sukhatme. Pp. xvi + 361, with line illustrations. Indian Council of Agricultural Research, New Delhi. (n.d.) Rs. 15 net.

The number of textbooks of applied statistics is still growing fast, and any addition to the ranks needs some special merit to deserve a place. Fortunately, these authors are exceptionally qualified: Dr. Sukhatme, internationally known for his work on sampling, is chief of the Statistics Branch of F.A.O., and Dr. Panse is his successor as statistician to the Indian Council of Agricultural Research.

The authors, addressing themselves to agricultural research workers and to senior students of agriculture and biology, rightly give most space to the principles and practice of field trials and to the elements of the statistical techniques these require. Their opening chapters deal with frequency distributions, the concepts of sampling, randomness and error, and with the outlines of significance testing, correlation and regression. The second and larger section of the book deals comprehensively with experimental design; the practical outlook is evident from such sections as those which discuss the merits and demerits of Latin square designs (p. 165), and the selection of trial sites and the dimension of plots (pp. 302–6).

The final chapter is of unusual interest, referring to experimental programmes consisting of large numbers of very simple trials, carried out on the land of peasant cultivators. Advice on the conduct and statistical aspects of such trials is not easily available, and a real gap is filled by this section, which should make the book of particular interest in agriculturally backward areas. The authors' insistence on selecting trial sites by random sampling methods may strike readers in some "advanced" countries as a counsel of perfection.

In any book of this size some topics must be omitted and others dismissed very briefly. It is a pity that the authors did not find room for some observations (which they are well placed to make) on presentation of numerical results and the just place of statistical information in research reports. Since the research worker needs to understand his colleagues' statistics as well as his own, the term "least significant difference" should have been introduced, perhaps on page 156, where it is defined under the alternative name of "critical difference."

In Chapter XV more attention could be given to systems of grading marks and the subjective pitfalls to be avoided when these are used; and, in the section on transformations, worked examples might have been included. The inverse-sine method in particular always puzzles the inexperienced.

The value and quality of the content of this book are occasionally marred by ungainly writing: "Instead of numbering the plants a research worker may number the rows and find out a random row with the help of tables of random numbers . . ." (p. 42). On page 332 an unintentional red herring is provided by the mention of "plots of 7·26 cents area": the units are not explained, nor do they appear in any reference book available to the reviewer.

These criticisms of detail do not affect the overall worth of the book as a useful introductory text, with a value of its own based on its numerous examples derived from typical Indian crops and conditions.

P. A. COLLIER

Mechanization of Tropical Crops. W. N. Bates, with a foreword by Dr. Cornelius Davies. Pp. xiii + 410, with line and halftone illustrations. Temple Press Ltd., London. 1957. 45s. net.

The growing subject of mechanization in tropical agriculture has not hitherto had any textbooks of its own. It is fortunate that the compilation of the first one has been undertaken by so competent an author as Mr. Bates, a former mechanical cultivation engineer to the government of Bombay Province. He is able to present an extraordinarily wide range of information from many parts of the tropics, and it is only rarely that his local knowledge lets him down, as where he supposes that rinderpest is now a problem in Malaya.

The majority of technical men employed in tropical agriculture are agronomists, and the approach in this book will be fresh to them, for it is that of an engineer. This will make it stimulating reading to many. The few factual errors that occur in the book are mostly botanical: *Eleusine* is not a sedge, derris and *Centrosema* are not annuals, *Fomes* and *Uredo* read oddly as the only diseases of cotton in the tropics considered worth mentioning, and exception may be taken to the spelling "rami" instead of the usual "ramie."

Part I of the book, rather misleadingly entitled "Food Crops," gives a general background for engineers of tropical crop production. Part II deals with particular aspects of mechanization and may be praised for the inclusion of a chapter on technical education. Part III, the longest, covers the mechanization of individual crops. Each chapter is prefaced by an elementary description of the crop, which seems rather uncalled for unless the reader has noted the statement in the preface that Part III is designed to give manufacturers details of the crops and the potential demand for machinery. In some chapters, such as that on pulses and legumes, there is more (as the author admits) about the crops than about their mechanization.

The time-lag between writing and publication has been creditably short, since the author's preface is dated October 1956 and the book was available early in 1957. This has enabled the author to present an account of developments in mechanization which is notably up to date and in most instances gives adequate weight to recent advances. Nevertheless it is the duty of a reviewer, of however good a book, to point out omissions or inadequacies, if only that they may be remedied in any subsequent edition. The single paragraph on mechanized plucking of tea does not do justice to the amount of experimental trials undertaken and makes no mention of Russian work; the description of cotton picking machinery is brief and omits cotton strippers; on page 227 the author does not seem to be aware that rice transplanting machines are already in use. Irrigation pumps, light railways on estates as compared with other modern methods of transport, and the many and ingenious Japanese hand- or foot-operated machines which can be applied to tropical agriculture might all have received consideration. The bibliography includes only works in English, and a notable omission is the Colonial Office report on mechanization of native agriculture in Africa published in 1950. Agricultural economists will not find much consideration of the economics of the various operations. This perhaps would demand a separate book; but there are some other broad problems of which mention might be expected. One is the importance and usefulness in the tropics of mixed cropping, which becomes almost impossible when mechanical harvesting is introduced. Another is the value of adapting crop varieties to mechanical handling; good examples are the choice of varieties of sorghum and castor for combine harvesting, neither of which is dealt with.

It is gratifying to have a book which brings out clearly the virtues of much British machinery in tropical agriculture, since so much of the literature deals largely with American products. The recent large-scale adoption of continental tractors in Brazil's very ambitious programme of mechanization shows that there is no room for complacency among British manufacturers.

It is not the author's fault that any book on this rapidly developing subject will date fairly quickly. But for an account of the present state of agricultural mechanization in the tropics Mr. Bates has given us as good a book as any one author can be expected to write. G. B. MASEFIELD

The Underground Organs of Herbage Grasses. (Bulletin No. 44. Commonwealth Bureau of Pastures and Field Crops.) A. Troughton. Pp. ix + 163, with line and half-tone illustrations. Commonwealth Agricultural Bureaux, Farnham Royal, Bucks, England. 1957. 25s. net.

The roots of a plant are just as important as the stems, leaves and flowers but their study is much more difficult, since they are within the soil and cannot be examined without disturbing their environment. For this reason our knowledge of root systems is generally much less than that of the aerial parts.

It is agreed that the most important crop in Britain is grass, and in recent years much effort has been devoted towards increasing the yield. Clearly knowledge of the part played by root systems of grasses is of fundamental importance, yet there has been little research in this country in the past and even now it is very limited. Foremost in this field is A. Troughton of the Welsh Plant Breeding Station, and all who are interested in grassland and alternate husbandry will be placed very much in his debt by the excellent and critical survey of the literature he has presented in this volume.

The book is divided into four parts—description of underground organs, factors influencing growth, the effect of the plant on the soil and methods employed in the study of underground organs. The first part describes in detail seminal and nodal roots and also underground organs other than roots, together with seasonal growth, distribution of roots in the soil and their chemical composition. The second part includes the influence of soil water, temperature and structure on root development and, in addition, the influence of defoliation and mineral nutrition. In the third section the part played by grasses in building up soil organic matter, in modifying soil structure and reducing soil erosion is described. Lastly, there is a brief account of the methods employed in studying root systems.

Although the book is primarily a survey of the literature, the information is skilfully arranged and presented in a stimulating fashion. The author makes it clear that much of the information about roots, particularly of factors influencing growth, is contradictory. It is always easy in such circumstances merely to present the conflicting data, but wherever possible suitable comments are made. Another notable feature is the inclusion of much valuable data, as yet unpublished, which the author has obtained from different parts of the world; it appears that most of the work on roots has been done in the U.S.A., New Zealand, Holland, Germany and Russia.

It is certain that this will be a standard book of reference. It would be helpful in a new edition if unified systems of measurements were used—preferably the metric. The chapter on soil water could also be revised with advantage. These are, however, minor points of criticism in an otherwise excellent book. A. J. LOW

A Textbook of Plant Virus Diseases. Kenneth M. Smith. Second Edition, revised. Pp. vii + 652, with line and half-tone illustrations. J. and A. Churchill Ltd., London. 1957. 65s. net.

The second edition of this reference book will be universally welcomed. Dr. Kenneth Smith, Director of the Agricultural Research Council's Virus Research Unit at the University of Cambridge, is one of the pioneers of the study of plant virus diseases and is a world-renowned authority on the subject. He has collected together in this volume much of the published information about the virus diseases of the world's plants and trees and the viruses causing them. Knowledge of the subject has increased greatly in the twenty years since the first edition was issued, so that this is virtually a new book. The text is concise and objective, which is indeed necessary in order to pack so much information in a volume of 650 pages. What is even more important is that it gives the information one is likely to look for in a book of this sort. Thirty-three pages of references in alphabetical order of authors point the way to more detailed information.

The arrangement of the book is businesslike. Without any preliminaries, the text starts with the heading "Abacá Bunchy-top Virus," lists its synonyms, describes the virus and its transmission, the diseases it causes, its host range, geographical distribution and control in one and a third pages. This is the general pattern for over 300 viruses from A to W. The common and more thoroughly investigated viruses are dealt with more fully. Cucumber Mosaic Virus is allocated twenty pages of text as well as numerous illustrations; the properties of the virus are described, the diseases it causes discussed for each host species grouped in families, and a description is given of the symptoms caused by each of the recognised distinct strains of the virus. Possibly some who have specialized on the pathology of a particular plant or on a virus would criticize the emphasis and detailed interpretation of the published literature; this is not a criticism of the book but a stimulus to the specialist to get his views and experiences publicised and accepted.

The popular English name is used for introducing each virus, and there is an index of synonyms. Alphabetical listing has not been made a fetish, so that "The Argentine Curly-top of Sugar Beet" comes in the middle of the "B's" among beet viruses, where one would expect to find it. Other awkward ones are dealt with by brackets—for instance Elm (American) Mosaic Virus and Hemlock (Poison) Ring Spot Virus and Bean (Southern) Mosaic Virus. None of these adopted names is listed in the index of synonyms, neither in its normal or convenient, bracketed sequence, which is perhaps a false economy of space.

The most important diseases are illustrated by reproduction of photographs in black and white on 92 plates. Most show what they should, but a few are from poor photographs or are too small. As diseases of one host are often described one after the other, the illustrations of diseases of one host plant might well have been grouped together instead of being dispersed.

Already an addendum includes nine viruses. Its inclusion demonstrates that the layout is adapted to the owner keeping his own copy up to date, and gives us hope that supplements will be published from time to time until eventually another revised edition is called for.

The book is clearly printed and well laid out on good-quality paper. It is strongly bound with a commanding title on the back, and is obviously built to withstand the hard wear and usage it will undoubtedly get.

The book will be a boon to all concerned with plants, whether growing or investigating them, advising or teaching those who hope to grow them. Many will join in saying "Thank you, Dr. Kenneth Smith!" R. HULL

Plant Protection Conference, 1956. (Proceedings of the Second International

Conference, Fernhurst Research Station England.) Pp. xi + 315, with line and half-tone illustrations. Butterworths Scientific Publications, London. 1957. 50s. net.

This conference fully maintained the high scientific and organisational standards set at the first in 1951. The aim was "to cover rather more fundamental aspects of crop protection," and sessions were held on genetics, mechanisms of action, systemic pesticides, user hazards and residue problems in food and soil, and methods of application. There were also excellent opening addresses by Dr. J. G. Knoll (F.A.O.) and Sir Frank Engledow (Cambridge). Prime contributors were drawn from the U.S.A., U.S.S.R., France, Netherlands and Sweden as well as from the U.K. and the Commonwealth. Specially full contributions were made on the problem of pesticide residues in foodstuffs by Fabre and Truhaut (Paris), and on the mechanics of producing sprays by Fraser (Imperial College, London).

Sir William Ogg commented: "The advances in plant protection have been outstanding. I do not know any subject which has made such extraordinary progress in such a short time." Thus at the 1951 conference only two oblique references were made to systemic insecticides, but in 1956 Metcalf reported about ten materials in commercial use and, moreover, gave many facts about their mode of entry and subsequent fate. However, no systemic fungicide of sufficiently high activity and low cost has yet emerged.

The view propounded in 1951 by Dr. Massee, that an ecological approach to insecticide development was necessary, now found expression at the highest levels when Sir Frank Engledow said: "All concerned must obviously accept what is now axiomatic among entomologists, that the entire insect population of a crop, indeed, of a locality in which the crop is situated, must be studied," and Sir John Russell expressed a similar view at the end of the session.

Dr. van der Kerk offered the interesting principle that "there is, I think, an intrinsic right of every plant to do with its metabolism what it can to get rid of foreign compounds." Apparently plants think so too! Jugoslav workers reporting on tests of chemicals for prevention of sprouting in potatoes, said: "Another unsatisfactory feature with products C and D was that the sprouts turned inward and grew so that they came out again at the other end of the tuber."

The trend of the conference came from the conviction that fundamental studies were the key to progress. Although Dr. van den Muijzenburg considered that "English people as a whole tend to profound scientific work," Sir Frank Engledow took the view that crop protection is far from being a subject in its own right for advanced teaching, and that good biologists, strong as chemists, and vice versa, are the best workers in this field.

The papers were provided to participants at the opening of the conference; as a result, the full report has been published in a matter of months. Errors seem to the reviewer to be few, but a number appeared in the preliminary copies as well. The closed-circuit television of slides was not very successful; many, but not all, are reproduced in the report.

A. H. M. KIRBY

ABSTRACTS

CROP PRODUCTION

Effect of Douglas-fir sawdust mulches and incorporations on soil microbial activities and plant growth. W. B. Bollen and K. C. Lu, *Proc. Soil Sci. Soc. Amer.*, 1957, **21**, 35–41.

Greenhouse studies were carried out to test the effects of various sawdusts, bark and cereal straws, both with and without supplemental nitrogen, on plant growth and soil microbial activity. All wood wastes and cereal straws at 100 ton/acre were found to depress yields and inhibit nitrification, but the induced nitrogen deficiency was less pronounced in the case of Douglas-fir sawdust, which is low both in available nitrogen and in carbon. The resins and other extractives from the Douglas-fir sawdust decomposed rapidly and had no direct toxic effect on either plants or soil micro-organisms and little effect on soil *p*H. To avoid nitrogen deficiency it is usual to recommend application of 5–10 lb. nitrogen per ton of sawdust, but in the case of Douglas fir additions to the soil and mulches at 10 ton/acre caused no decline in test crop yields. In the field when applied at 80 ton/acre to strawberries without supplemental nitrogen no decrease in yield was shown, but maize appeared sensitive to induced nitrogen deficiency.

E.M.A.

The nodulation of annual leguminous crops in Malaya. G. B. Masefield, *Emp. J. exp. Agric.*, 1957, **25**, 139–50.

The mean number of nodules per plant in samples of 20 plants are tabulated for cowpea (*Vigna unguiculata*), French bean (*Phaseolus vulgaris*), groundnut (*Arachis hypogaea*), *Psophocarpus tetragonolobus*, soya bean (*Glycine soya*), yam bean (*Pachyrhizus erosus*), pea (*Pisum sativum*), green gram (*Phaseolus aureus*), *Canavalia gladiata*, *Dolichos lablab* and *Voandzeia subterranea* from various regions. Both in the lowlands and in the relatively cool climate of the Cameron Highlands the degree of nodulation was very low compared with legumes in other countries, but much higher weights and numbers of nodules were attained on soils with a high water table (usually adjacent to paddy lands). A field test on cowpeas at Serdang showed that mulching with grass tripled the nodule weight; watering daily except on days of heavy rain gave a slight increase over the control; hand forking before sowing in addition to normal cultivation gave a marked decrease in nodulation. The rare crop *Psophocarpus tetragonolobus* was found to nodulate more heavily than any other legume examined; on a soil with a high water table 21 gm. of nodules per plant were recorded, equivalent to over 6 cwt./acre.

S.F.A.

The effect of rate and time of application of nitrogen on the yield of winter wheat. G. A. Blackett, *Emp. J. exp. Agric.*, 1957, **25**, 19–23.

Cappelle wheat was sown at Craibstone in autumn 1954, following early potatoes. The nitrogen dressings compared were 30 lb. N/acre at sowing, 30 lb. in late March, 30 lb. in late May, 15 lb. in late March and 15 lb. in late May, 30 lb. in late March and 30 lb. in late May, and control (no N); the nitrogen was given as 'Nitro-Chalk.' Grain yields of control plots and plots receiving N in autumn were 21 cwt./acre; 30 lb. N in spring gave 31–32 cwt./acre, regardless of the time of application; 60 lb. N in spring gave 42 cwt./acre. Yields of crude protein in the grain were 1·6 cwt./acre for control and N in autumn, 2·3 cwt. for 30 lb. N in spring, and 3·2 cwt. for 60 lb. N in spring, but the percentage nitrogen content of the grain tended to be depressed by 30 lb. N in spring, especially when half or all was given in March. 1000-corn weights were unaffected by any treatment. Number of ear-bearing plants, straw yield, and straw height were greatest after 60 lb. N in spring; 30 lb. N in March gave considerably higher figures than 30 lb. N in May, and 15 lb. N at each time gave intermediate values; N in autumn had no effect. S.F.A.

Effects of nitrogen applied at different dates, and of other cultural treatments on eyespot, take-all and yield of winter wheat (field experiment, 1953). G. A. Salt, *J. agric. Sci.*, 1957, **48**, 326–35.

Squareheads Master 13/4 or Cappelle was sown at 1½ or 3 bu./acre on 17th October 1952 at Rothamsted on the same plots as the 1952 experiment. 0, 2 or 4 cwt./acre ammonium sulphate was applied on 24th October, 5th March, 11th April or 22nd May. The plots that in the previous experiment had not been sprayed with sulphuric acid were sprayed on 4th March 1953 at 85 gal./acre of 12½%B.O.V. Eyespot was less on Cappelle than on Squareheads Master and was less with the low seed rate; amount and date of nitrogen top-dressing and March spraying with sulphuric acid had no effect on eyespot. Take-all was more severe on Cappelle than on Squareheads Master; by harvest it ranged from 8·7% in thinly sown plots with 4 cwt./acre ammonium sulphate to 69·2% in thickly sown N-deficient plots. Nitrogen applied soon after spraying had little effect on take-all, whereas it greatly decreased the extent and severity of infection on unsprayed plots; on the plants which received no N, however, spraying decreased the incidence of take-all; it is suggested that defoliation after spraying may have decreased the beneficial effect of N, whereas on the no-N plots spraying may have reduced competition for nutrients by weeds. Sulphuric acid spray in March killed cleavers (*Galium aparine*) but not persicaria (*Polygonum persicaria*) and knotgrass (*P. aviculare*); nitrogen top-dressing reduced weed on thickly sown plots, probably by reducing take-all, but had no effect on thinly sown plots; weeds were more severe in Cappelle than in Squareheads Master; seed rate had no effect on weed incidence, possibly because thin seeding reduced the incidence of take-all. Cappelle did not lodge; lodging of Squareheads Master was increased by N and decreased by spraying; the effects of seed rate and of date of N application did not show a consistent trend. The two rates of ammonium sulphate increased the mean yield of Squareheads Master by 4·1 and 5·3 cwt./acre and of Cappelle by 4·3 and 6·1 cwt./acre; halving the seed rate increased yield by amounts ranging from 8·3 cwt. in N-deficient plots to 2·6 cwt./acre in high-N plots; spraying increased the yield of plots receiving no N or N in October but depressed the yield of plots receiving N in May; yield in thinly sown plots was least when N was applied in March and increased with later applications, but in thickly sown plots yield was greatest when N was applied in March and decreased with later applications. S.F.A.

Experiments on seed rates, nitrogen rates for spring barley 1952-3-4. G. K. Rennie, *Exp. Husb.*, 1957, (2), 12–17.

The effects of seed rates of 1, 1½, 2 and 2½ cwt./acre and nitrogen rates of 1, 2 and 3 cwt./acre of 'Nitro-Chalk' in the seedbed on Kenia, Earl and Plumage Archer were investigated at High Mowthorpe Experimental Husbandry Farm. All three varieties responded similarly to varying seed and nitrogen rates. Seed rates higher than 1 cwt./acre did not result in any increase in yield but reduced the vigour of the individual plants, the number of tillers per plant, the standing power of the crop, and the 1000-grain weight. Nitrogen application in all cases increased yield, each successive cwt. 'Nitro-Chalk' yielding 2 cwt. grain. The high N rates, however, resulted in some lodging, particularly in Earl, and increased the N content of the grain. S.F.A.

The fertilizer requirements of sugar beet. D. A. Boyd, H. V. Garner and W. B. Haines, *J. agric. Sci.*, 1957, **48**, 464–76. **The manuring of sugar beet.** D. A. Boyd, *Ibid.*, 477–80.

The results of 360 experiments carried out in England and Scotland over the years 1934–49 for the Sugar Beet Research and Education Committee by Rothamsted Experimental Station, the agriculturists attached to the sugar beet factories and the County Agricultural Organizers indicated that for most beet-growing soils other than fen peats the optimal dressings per acre in the absence of farmyard manure were 1·0 cwt. N or more, 0·5 cwt. P_2O_5, 1·5 cwt. K_2O or more in the absence of salt (but little or no potash in the presence of salt), and 5 cwt. salt (whether or not potash was applied). The survey of fertilizer practice carried out by the N.A.A.S. Provincial Soil Chemists in collaboration with Rothamsted included sugar beet in several counties in England in 1952 and 1954. The percentage of acreage receiving farmyard manure was about 60% in Shropshire, Northants, Suffolk and Yorks, 30% in Norfolk and Essex, 20% in Lincs, and 10% in Ely. When allowance is made for the nutrients in the farmyard manure, the average amounts of nitrogen and potash applied were not far from the optimal amounts, whereas the average amounts of phosphate were about twice the requirements. The average N, P and K applications in all the districts except Isle of Ely were very similar, but there was a very wide range of practice from farm to farm, each nutrient covering the whole range from nil to over 2 cwt./acre. Salt was used on 50–70% of the beet in Shropshire, 25% in Yorks, and an average of 6% elsewhere. Excessive dressings of phosphate and failure to use salt are attributed to the growers' strong preference for compound fertilizers. S.F.A.

Studies on lucerne and lucerne-grass leys. IV. The effect of systems of grazing management on the persistence of a lucerne-cocksfoot ley. M. G. Barker, F. Hanley and W. J. Ridgman, *J. agric. Sci.*, 1957, **48**, 361–6.

In 1949 the following treatments were compared on a lucerne-cocksfoot ley at Cambridge undersown in spring 1948 in winter wheat; grazed by sheep at intervals of 2, 4 or 8 weeks throughout the season (24 weeks): cut for hay after 8 weeks, then grazed at intervals of 2, 4 or 8 weeks; grazed at intervals of 2, 4 or 8 weeks until the end of the 16th week, then rested 8 weeks before cutting for hay; cut three times at intervals of 8 weeks. Defoliation at intervals of 8 weeks maintained a satisfactory balance of lucerne, irrespective of whether defoliation was by cutting, by grazing, or by a combination of the two. Grazing at intervals of 2 or 4 weeks seriously reduced the proportion of lucerne in the sward; a rest of 8 weeks early or late in the season had little effect on the proportion of lucerne. The same treatments were continued on the same plots for a second year, and some of the treatments were applied to additional plots that in 1949 had been cut three times for hay. By spring 1951 the only plots in either experiment to show appreciable quantities of lucerne were those which had been defoliated at intervals of 8 weeks. Frequent defoliation encouraged profuse tillering of cocksfoot. S.F.A.

CROP PROTECTION

Aphid resistance to parathion. V. M. Stern and H. T. Reynolds, *Calif. Agric.*, 1957, **11**, (2), 4, 14.

Failures of parathion and malathion to control the spotted alfalfa aphid, *Therioaphis maculata*, in California were reported in increasing numbers during the summer of 1956, although the areas in which resistant strains of the aphid occurred were limited. In comparative trials it was found that Trithion (*p*-chlorophenyl thiomethyl ester of *o,o*-diethyl dithiophosphoric acid), Phosdrin (2-carbomethoxy-1-methylvinyl dimethyl phosphate) and an experimental insecticide gave good control of resistant aphids, but parathion was superior to those materials against non-resistant strains. Phosdrin had little residual activity: at 0·6 oz./acre control dropped from 99·8% to 89·9% within 72 hours of application. Trithion at 4 oz./acre was satisfactory. The resistance to parathion is in an early stage of development, and it is not known whether it will eventually extend to other organic phosphorus insecticides. D.L.

Translocation of BHC from high-dosage soil treatments applied before planting. J. H. Lilly and J. E. Fahey, *J. econ. Ent.*, 1956, **49**, 815–18.

Measurable amounts of BHC were detected in seeds of various crops for three years after soil applications of lindane at 50 lb./acre in 1952. The crops represented three plant families, and included those with seeds of both high and low oil content. Soya bean samples showed BHC at rates of 0·74, 0·89, 0·27 and 1·21 p.p.m. in 1952, 1953, 1954 and 1955 respectively. Results obtained with dent corn were less consistent, but sweet corn seed gave values of between 0·41 and 0·71 p.p.m. Sweet corn also showed from 0·02 to 0·37 p.p.m. after pre-planting soil treatment with γ-BHC at 10 lb./acre. Sunflower, sorghum and garden beans all indicated translocation of BHC from the soil when it was used at 50 lb./acre, but results from applications at 10 lb./acre were not so conclusive. Samples of beans grown from seed containing 0·13 p.p.m. lindane and planted on untreated soil showed questionable traces of the insecticide. Germination of all seeds was unaffected, no taint occurred, and flour beetles feeding on grains were not killed. It is concluded that translocation would never cause residues to accumulate in plants at concentrations approaching the U.S. official tolerances of 10 p.p.m. for lindane and 5 p.p.m. for BHC. D.L.

Über Thiodan, ein neues synthetisches Insektizid. (Thiodan, a new synthetic insecticide.) W. Finkenbrink, *NachrBl. dtsch PflSchDienst., Braunschweig*, **8**, 183–5.

Thiodan is a sulphurous heterocyclic hydrocarbon (6,7,8,9,10,10-hexachloro-1, 5,5*a*,6,9,9*a*-hexahydro-6,9-methano-2,4,3-benzodioxathiepin-3-oxide) that has been developed in Germany. Two isomers exist, but they do not differ in their insecticidal activity. World-wide trials have shown that Thiodan is effective against many crop pests and against insect and mite parasites of animals, but a certain selectivity has been noticed. Aphids, most lepidopterous larvae, carrot fly, and onion fly are well controlled by Thiodan at 0·02%; the migratory locust, Psyllids, and coleopterous larvae require 0·03%; cabbage fly, crickets, mange mites, and corn earworm are progressively less susceptible, and cockroaches and grain weevils require concentrations of 0·1% for satisfactory kills. Thiodan was inadequate for use against red-spider mites. It is not yet clear whether the insecticide works as a contact or stomach poison, and only dust formulations have been used. Field trials with soil applications have given promising results in the control of white grubs, wireworms, and crane-fly larvae. No phytotoxicity has been reported, nor has Thiodan caused tainting of root crops. Its mammalian toxicity is low; the acute oral LD_{50} for rats is about 40–60 mg./kg. Thiodan is less volatile than γ-BHC and the action of its vapour phase is slight. D.L.

The relationship of saprophytic antagonism to control of *Botrytis cinerea* Pers. on tomatoes. F. J. Newhook, *N.Z. J. Sci. Tech.*, (A), 1957, **38**, 473–81.

Strains of saprophytic fungi (*Cladosporium herbarum*, *Penicillium* sp. and *Alternaria* sp.), isolated from dead tomato petals, gave complete control of *Botrytis cinerea* on tomatoes when inoculated as pure or mixed cultures on to sterilized petals 3–5 days before infection with *B. cinerea*. Natural infection of fruit trusses by *B. cinerea* was 46–80%, and this was reduced to 1–3% by the establishment o *C. herbarum* and *Penicillium* sp. on dead petals adhering to fruits after the use of a fruit-setting spray. Although a considerable degree of protection was thus given under glasshouse conditions, it was found that several weeks could elapse before protection built up to an effective level. Protection was greatest on the first 3 trusses; considerable loss still occurred on upper-truss flowers and young fruit. D.L.

The use of antibiotics and fungicides in mist propagation. R. E. Skiver, *Plant Dis. Reptr*, 1956, **40**, 1074–80.

Control of alternaria blight, caused by *Alternaria dianthi*, was attempted on carnation cuttings rooted by means of a mist-propagating system. Control materials were first tested *in vitro* against the organism. Selected fungicides were sprayed with the mist, the solutions being pumped from a storage tank into the tap-water supply for 4–5 seconds out of each minute. The cuttings were inoculated after the first day of mist application and examined after three weeks. Alternaria blight was significantly reduced by the following materials: captan, 19 p.p.m.; tomatine, 2 p.p.m.; Omadine 1456 (2-pyridinethione 1-oxide disulphide derivative), 10 p.p.m.; Omadine 1483 (thiourea derivative of pyridinethione), 2 p.p.m.; and Omadine 1564 (2-pyridinethione 1-oxide, manganese salt), 2 p.p.m. Actidione at 2 p.p.m. caused stem collapse. Rust caused by *Uromyces caryophyllinus* was also examined, but it appeared to be of little importance under the conditions of mist propagation encountered in the experiments. D.L.

Effect of antibiotics and surface-active agents on bacterial wilt of sweet corn in the greenhouse. L. E. Williams and J. L. Lockwood, *Phytopathology*, 1957, **47**, 44–8.

Terramycin or Actidione sprayed on maize seedlings at 50 p.p.m. reduced the incidence of symptoms of bacterial wilt induced by inoculation with *Bacterium stewartii* 24 hours later. Streptomycin and penicillin at the same concentration were ineffective. Actidione was very phytotoxic. Wilt control by terramycin and streptomycin was enhanced when plants were held in a moist chamber for 24 hours after having been sprayed, but it was not improved when 10,000 p.p.m. glycerol was added to the spray. Wilt was partially inhibited by the use of surface-active agents at 10,000 p.p.m.; Triton X-114 was effective at 1000 p.p.m. and very phytotoxic at 10,000 p.p.m. Maximum control by Tween 20 was given when it was sprayed to both leaf blades and the whorl. D.L.

Suppression by two substituted carbamates of symptoms induced by southern mosaic virus. (Abstract.) F. M. B. Porter, C. Smale, W. H. Preston and J. W. Mitchell, *Phytopathology*, 1957, **47**, 27.

The application of either furfuryl 5-chloro-2-methylcarbanilate or furfuryl carbanilate to Pinto bean plants infected with southern mosaic virus resulted in almost complete suppression of symptoms without apparent injury to the plants. For pre-inoculation treatment to be effective a volatile and a non-volatile carrier required to be incorporated, and some injury was then caused. D.L.

Plant parasitic nematodes in soil biology. G. Thorne, *Proc. Soil Sci. Soc. Amer.*, 1957, **21**, 1–2.

Although in recent years the significance of the effects of eelworms on agricultural and horticultural crops has been realized, the study of nematodes is still at the level of plant pathology in 1910 and of economic entomology in 1890. In the United States eelworms have been as important as soil erosion and depletion in rendering land worthless for cultivation, and it is probable that because of their activities the actual production potentials of many areas have never been appreciated. The full value of fertilizers is not reflected in yields because a considerable portion is deflected to replace roots destroyed by eelworms, and this is especially true in certain areas of the Great Plains, where huge populations of the dagger nematode (*Xiphinema americanum*) occur. Many of the Experiment Station sites in the United States are so infested that field data on yields are probably worthless. Control of eelworms by soil fumigation has given good results with field crops, but repopulation from survivors can increase at such a speed as to reduce yields by harvest time. The narrow borderline between dosages lethal to nematodes and to plants makes soil fumigation of lesser value with such perennial crops as fruit trees. D.L.

Lucerne stem eelworm. A serious threat to lucerne growing. E. B. Brown, *Agriculture, Lond.*, 1957, **63**, 517–20.

A serious view is taken of the lucerne stem eelworm (*Ditylenchus dipsaci*) problem in England and Wales, particularly with the increased sowing of from 30,000–40,000 acres before the war to a present 111,000 acres. The spread of the eelworm in fields is rapid: patches of infested plants measuring 1 ft. across may measure 18 ft. across by the following season. In dry seasons the spread is restricted, but with frequent rain there is a striking increase in incidence. Varietal differences in resistance have been noted, Hungarian and French varieties being most susceptible. The only other known crop hosts in Britain are alsike and sweet clovers. Seed fumigation with methyl bromide is a feasible method of preventing the introduction of the eelworm, but field eradication is extremely difficult. Ploughing up the infested field is a certain but drastic method, and is thought to be scarcely justified for fields with isolated patches of infested plants. Flame-gunning has been suggested in the Argentine, but it is not wholly effective. Two American varieties are resistant to attack, but neither of them is suited to British conditions; nevertheless, the possibilities of breeding resistant varieties may have to be considered if the eelworm continues to spread at its present rate. D.L.

The effect of chemical treatments on root-knot nematodes in the Gold Coast. F. C. Peacock, *Emp. J. exp. Agric.*, 1957, **25**, 99–107.

Although the nematicidal effect of ammonia has long been known, field populations of root-knot eelworms (*Meloidogyne* spp.) on tomatoes in Ghana were only slightly reduced by two top-dressings of sulphate of ammonia applied at 1 cwt./acre each. Calcium cyanamide, urea, muriate of potash and superphosphate were ineffective, although the first two fertilizers had shown promise in pot tests. Soil injections with DD-mixture, ethylene dibromide and crude tetrachlorobutadiene all gave excellent control of root-knot on tomatoes in the field. With DD-mixture the following crop only was protected; with the other two toxicants there was a residual effect on a second eelworm-susceptible crop. D.L.

Simazin and related triazines as herbicides. C. Bartley, *Agric. Chemic.*, 1957, **12**, (5), 34–6, 113–15.

Four tables indicate the efficiency of Simazin (2-chloro-4,6-bis(ethylamino)-s-triazine) and Chlorazin (2-chloro-4,6-bis (diethylamino)-s-triazine), together with three other Geigy experimental triazine compounds, for which the chemical structures are shown, as pre- and post-emergence weedkillers on both broad-leaved and grassy weeds, and the tolerance to these chemicals of fifteen crops, including maize, wheat and cotton. In pre-emergence tests Simazin applied at ½, 1, 2, 4, 8 lb./acre and the other triazine compounds at 2, 4, 8 lb./acre were superior to standard weed control chemicals Sinox, CIPC and CDAA. Simazin at 1 lb./acre proved very effective and gave 99% control of broad-leaved weeds and 86% control of grassy species for ten weeks. At rates higher than 1 lb./acre Simazin injured all treated crops except maize. In post-emergence tests in which Simazin was applied at the same rates as the other triazine compounds, viz. 2, 4, 8 lb./acre, it exhibited less activity. The outstanding value of Simazin appears to be as a pre-emergence weedkiller in maize with possible application in such crops as tomatoes, potatoes, asparagus and grapes. E.M.A.

The loss of activity of 2,4-D as a pre-emergence weedkiller. A. G. Barrie, *Cane Gr. quart. Bull.*, 1956, **20**, 39–40.

Leaching of 2,4-D from three N. Queensland soils—a red volcanic, a red-brown schist and an alluvial soil—was studied in soil columns in pliofilm tubes and the possible deleterious effects of heavy applications of the herbicide on sugar cane roots were discussed. After spraying the equivalent of 2 in. rainfall on to the soil surfaces it was found that the 2,4-D was distributed fairly evenly over the top three inches of soil and small amounts penetrated to the fifth inch layer of the red-brown schist and the sixth inch layer of the red volcanic soil. It was also shown that in a sandy loam soil well supplied with organic matter and incubated over a period of six weeks the action of micro-organisms caused an almost complete disappearance of 2,4-D, suggesting that the weedkiller would fail to control weeds effectively in soils harbouring bacteria capable of decomposing 2,4-D. E.M.A.

Influence of 2,4-D on the uptake of minerals from the soil. A. R. Cooke, *Weeds*, 1957, **5**, 25–8.

The effect of 2,4-D on the uptake of potassium, chlorine, calcium and sulphur from the soil by bean plants was studied. Beans having fully expanded primary leaves were sprayed with a non-herbicidal concentration of 2,4-D of 100 mg./l. Immediately after spraying, the four nutrients potassium (K^{42} in the form of $K^{42}CO_3$), chlorine (Cl^{36} in the form of KCl^{36}), calcium (Ca^{45} in the form of $Ca^{45}Cl_2$) and sulphur (S^{35} in the form of $H_2S^{35}O_4$) were added to the soil and samples of plant tissue from primary leaf blades, petioles, shoot tips, epicotyls and hypocotyls were taken at several intervals and nutrient uptake determined by their radioactivity. Treatment with 2,4-D caused a large increase in potassium uptake after a few hours but at the end of 24 hours had greatly inhibited it. During the first 12 hours treated plants showed increased uptake of chlorine also, but at the end of 48 hours control plants were shown to contain approximately twice as much of this nutrient. Treatment stimulated calcium uptake for nearly 48 hours, after which it became apparent that 2,4-D was beginning to inhibit calcium uptake in most tissues also. The effect of 2,4-D on enhancing sulphur uptake was slight, and at the end of 24 hours treatment had greatly inhibited uptake from the soil. The changes in uptake of minerals from the soil as a result of spraying with 2,4-D are not considered as being directly related to the primary herbicidal action of the chemical, but the results are discussed in relation to the effect of 2,4-D on plant respiration. E.M.A.

A comparison of MCP and 2,4-D for the control of annual weeds in grain crops. H. A. Friesen and D. R. Walker, *Canad. J. Plant Sci.*, 1957, **37**, 69–81.

Results are given of trials carried out at a number of experimental farms in western Canada during 1954 and 1955 to compare applications of 2,4-D amine, ester and low volatile ester with MCPA sodium salt, amine and ester applied at rates of 4 and 8 oz. acid equivalent per acre to weeds in the seedling stage and at bud appearance of the major weed species in oats, flax and barley. The predominant weeds are listed, and control by the different formulations of 2,4-D and MCPA is compared. Five tables are given to show yields of oats and flax together with weed counts and dry weights of weeds per acre at the different centres. On the basis of weed control and crop yield the results favour the use of MCPA over 2,4-D. Oats were significantly more tolerant to MCPA than to 2,4-D, particularly when treated at the early stages of growth, when weed competition is most critical: difference in tolerance by flax was most pronounced in favour of MCPA at the later date of treatment. 2,4-D ester and low volatile ester both caused abnormalities in plant growth and lower yields in oats and flax and also delayed maturity of flax significantly. Barley yields were unaffected by the spray treatments at the particular dates in these trials. E.M.A.

A new development in selective weed control. G. B. Lush and E. L. Leafe, *Proc. 3rd Brit. Weed Control Conf.*, 1956, 625–32.

Certain substituted phenoxy propionic acids were found to be active against cleavers (*Galium aparine*). Two compounds, α-(2,4-dichloro-3-methyl phenoxy) propionic acid (2,4-DMP) and α-(4-chloro-2-methyl phenoxy) propionic acid (MCPP), at 2 lb. acid equivalent/acre gave a cleavers control comparable to that given by DNC; although the action was slower with the propionics, the final effect was the same. The optimum stages to spray cleavers were from the 3–4 internodes stage up to flowering. The best results were obtained with the chemical in 50 gal. of water/acre, but they were almost as good in 20 gal./acre. 2,4,5-TP also controlled cleavers, but was considerably phytotoxic to cereals. Only the dextrorotary isomer was found to be active, but the active acid equivalent here refers to the mixed dextro- and laevo-rotary isomers. MCPP at 2 lb. acid equivalent/acre controlled a range of weeds as satisfactorily as did MCPA at 1–2 lb. acid equivalent/acre; 2,4-DMP was practically specific to cleavers. MCPP and MCPB were applied to wheat, barley and oats at 1–4 lb. acid equivalent/acre in 20 gal. of water; there was no appreciable damage with either when applied between the first- and seven-leaf stages. 2,4-DMP and 2,4-DP caused damage when applied at the same rates and stages. The phenoxy-propionic compounds have a very low mammalian toxicity, and the amine formulations used were readily miscible in water. R.A.U.

Control of hormone resistant weeds in cereals. T. C. Breese and A. F. J. Wheeler, *Proc. 3rd Brit. Weed Control Conf.*, 1956, 759–65.

Sodium monochloroacetate (MCA) was compared, in replicated trials, with DNC for the control of cleavers (*Galium aparine*) in cereals. 20 and 25 lb./acre gave a consistently good cleavers control; low-volume application of 20 gal. of water/acre gave a better control than high-volume application, but the volume did not appear to affect the cereal yield. 20 lb. in 20 gal./acre also gave efficient control of redshank (*Polygonum persicaria*), daynettle (*Galeopsis tetrahit*) and charlock (*Sinapis arvensis*) and checked the advanced seedling stage of chickweed (*Stellaria media*) and field bindweed (*Convolvulus arvensis*) and all growth stages of creeping thistle (*Cirsium arvense*) and coltsfoot (*Tussilago farfara*). MCA at 20 lb. in 20 gal./acre caused no significant yield depression in autumn-sown and winter-sown wheat, oats or barley, or in spring-sown wheat or oats, when they were sprayed below 9 in. in height; 25 lb./acre caused a slight yield depression, especially in spring wheat. In one trial 20 lb. in 20 gal./acre caused an 18% yield depression in spring barley. MCA and MCPA mixtures were not synergistic. The addition of 0·25% concentration of Agral LN had no effect on the performance of MCA at either high or low volume. MCA was slightly inferior to DNC in its all-round effect on hormone-resistant weeds, but was far more convenient to use. It is a soluble powder, relatively non-toxic to mammals, and acts as a contact weed-killer. R.A.U.

The effects of MCPB and 2,4-DB on seedling and established clovers. J. G. Elliott, *Proc. 3rd Brit. Weed Control Conf.*, 1956, 465–75.

Seedling S.100 white clover was sprayed with MCPB 2,4-DB, MCPA and 2,4-D at 1, 2 and 4 lb./acre. When applied between emergence and the second trifoliate leaf stage 2,4-DB gave a greater yield of top growth than MCPB, but when applied at the 4–6 trifoliate leaf stage there was no significant difference between the chemicals. Both MCPA and 2,4-D greatly reduced the stand of S.100 white clover sprayed at the 4–6 trifoliate leaf stage. MCPB and 2,4-DB at 2 and 4 lb. in 100 gal./acre did not give significantly different yields of top growth of Cotswold broad red clover sprayed from emergence to second trifoliate leaf stage. The seedling white clover became more resistant to MCPB and 2,4-DB with increasing age, whereas the red clover was more resistant before the expansion of the first trifoliate leaf. Established S.100 white clover, some sown and some in permanent pastures, was sprayed with MCPB, 2,4-DB, MCPA and 2,4-D at 1, 2 and 4 lb. in 12 gal./acre. At no rate had MCPB and 2,4-DB any significant effect on the amount of clover leaf or the number of flowering heads present. MCPA and 2,4-D both produced significant reductions at 2 and 4 lb./acre. The general conclusions were that MCPA was most damaging to clover, and that 2,4-D was slightly less toxic. MCPB and 2,4-DB were considerably less toxic than either of the "acetics." R.A.U.

The effect of MCPB (sodium 2-methyl, 4-chlorophenoxybutyrate) on young red clover (*Trifolium pratense*) and weeds. D. B. Edmond, *N.Z. J. Sci. Tech. A.*, 1956, **38**, 397–402.

The action of the sodium salt of MCPB sprayed at rates of 0, 1, 2, 4, 6 lb./acre acid equivalent on a red clover sward which had reached a height of 4 in. after a second mowing was compared with the sodium salt of MCPA (30% acid equivalent) at a rate of 1 lb./acre acid equivalent. Strips from the experimental plots were harvested at four dates for yield data and visible effects of the treatments recorded. Red clover yield was significantly reduced by MCPA, but not by MCPB, though this chemical caused leaf scorch and petiole distortion of later leaves. A list is given of susceptible weed species on which both chemicals initially took effect with equal speed, but later MCPB appeared slower and less severe in action. It appears that 2 lb./acre MCPB has the same general effectiveness as 1 lb./acre MCPA, and it is concluded that while MCPB at 1 lb./acre does not harm the red clover it is ineffective at that rate in controlling weeds. E.M.A.

Weed control in seedling lucerne. S. A. Evans, *Exp. Husb.*, 1957, (2), 67–71.

Preliminary field trials at seven N.A.A.S. experimental husbandry farms showed that the ammonium salt of dinoseb (2,4-dinitro-6-sec butyl phenol) at 0·85 or 1·71 lb./acre had no adverse effect on lucerne with at least four true leaves, whereas 2·55 lb. dinoseb reduced the yield of the first cut of lucerne at three of the centres. In 1952 dinoseb and CIPC (isopropyl-N-(3-chlorophenyl) carbamate) were compared in a single field trial; pure lucerne heavily infested with chickweed was sprayed in November. The chickweed was controlled by dinoseb at 1·72 or more lb./acre but not by 0·85 lb.; all rates of CIPC (1, 2, 4, 8 lb./acre) were effective, but only after about 18 weeks. No treatment caused appreciable mortality of lucerne, but 4 and 8 lb. CIPC severely checked growth. At three centres in 1953 lucerne/grass mixtures heavily infested with weeds were sprayed in June (when the lucerne was at or beyond the four-leaf stage) with dinoseb or CIPC. A month later it was found that dinoseb had controlled annual sowthistle (*Sonchus oleraceus*), mayweed (*Matricaria* sp.), charlock (*Sinapis arvensis*), fat hen (*Chenopodium album*), field scabious (*Knautia arvensis*) and poppy (*Papaver rhoeas*) but not chickweed (*Stellaria media*) or white campion (*Melandrium album*); CIPC gave good control of chickweed, stunted but did not kill charlock, fat hen and annual sowthistle, and had no effect on mayweed. Better results would probably have been obtained from CIPC if the assessments had been made after two months as well as one month. Dinoseb sometimes caused slight checking or scorching of the lucerne, but recovery was rapid; all rates of CIPC caused yellowing and 4 and 8 lb./acre also caused stunting. At one of the two centres where yields of the first cut in 1954 were measured CIPC at 2, 4 and 8 lb./acre reduced green weights, whereas dinoseb at 1·28 and 1·7 lb./acre increased yields (at this centre the predominant weed had been annual sowthistle). S.F.A.

Chemical treatment of bracken, *Pteridium aquilinum*. E. Conway and J. D. Forrest, *Proc. 3rd Brit. Weed Control Conf.*, 1956, 255–68.

During the summers of 1955 and 1956 replicated experiments were carried out on bracken plants. Various herbicides were applied as foliar sprays to one-year-old plants in garden beds and to mature stands of field bracken; soil applications were also made. Ammonium sulphamate at 25 lb. in 100 gal. of water/acre killed the young fronds by contact; it was almost certainly translocated and slightly inhibited the rhizome growth. The fronds of mature plants were killed by an August application of 35 lb./acre, but there was no effect on the rhizome growth. June applications of amino-triazole alone at 10–40 lb./acre and at 5 lb./acre + 1 and 2 lb./acre of 2,4,5-T (ester) affected the mature plants in the same way as ammonium sulphamate. The phenoxyacetic and phenoxybutyric compounds, all at 500 p.p.m., had marked systemic effects on the rhizome of young plants; there was differentiation of the apical tissues, but this was seldom lethal. The most interesting morphological effects were induced by 2,4,5-T and 4-CPA, both of which restricted the rhizome development, and by 2,4,5-TB, which caused internodal elongation. A June application of MCPB at 8 lb./acre to mature plants caused epinastic curvature of the fronds unfurled at the time of spraying. There was no translocation into the rhizomes of mature plants with any of the substances tested. Soil applications were made in the spring before frond emergence with ammonium sulphamate at 75 lb./acre, TCA (sodium salt) at 75 lb./acre, amino-triazole at 20 lb./acre, maleic hydrazide at 15 lb./acre and CMU at 60 lb./acre. The dead bracken litter was burned before all treatments. All chemicals acted as contact herbicides on the developing fronds; this was most marked with the ammonium sulphamate. In all cases the rhizomes were normal, but no work was done on cumulative effects or on soil persistence. No chemical treatment was lethal or more effective than mechanical cutting or crushing. R.A.U.

ANIMAL HUSBANDRY

The effect of low-level and therapeutic administration of phenothiazine on the color of cow's milk. J. E. Alicata and O. Wayman, *Vet. Med.*, 1957, **52**, 18–20.

Phenothiazine mixed with concentrate feed and given to 13 lactating cows at the rate of 2 g./day did not cause discoloration of the milk among 12 animals producing 8·2–24·3 lb. milk daily, but one cow having an output of 4·3 lb. per day developed slight pink discoloration of the milk. Therapeutic doses of 60 g. phenothiazine administered to four lactating cows producing 12·8–19·3 lb. of milk per day resulted in discoloration of the milk during the first two days. The milk, however, resumed its normal appearance on the third day. It is concluded that low-level phenothiazine feeding may be safely instituted among dairy cows which are not near the end of the lactation period, and under conditions where they are kept in pastures which are also used for the grazing of young stock. The recommended therapeutic dose of phenothiazine does produce milk discoloration for the first two days, and such milk should be withheld from distribution for at least two days. J.T.E.

Sulfaquinoxaline and Sulfamerazine in the treatment of experimental infections with *Eimeria bovis* in calves. D. M. Hammond, J. L. Shupe, A. E. Johnson, P. R. Fitzgerald and J. L. Thorne, *Amer. J. Vet. Res.*, 1956, **17**, 463–70

At the Utah Agricultural Experiment Station the authors infected 4 lots each of 12 calves aged 8–25 days with coccidia, of which 90% were *Eimeria bovis*. The oocysts were administered through a nippled flask and the total infective dose per calf was either half or one million oocysts. Eighteen of the calves were untreated infected controls. The treated calves received one or two 4-day courses of treatment either at the rate of 1, ½, ½, ½ or 1, 1, ½, ½ grain/lb. The results make it clear that deaths from acute coccidiosis do not constitute the sole criterion of success or failure in treatment, since the untreated control calves did not show a uniform heavy mortality rate. The most important experimental finding was that a 4-day course of treatment appeared to be most effective when given on the 13th day after infection. Sulfamerazine appeared to be slightly more effective than Sulfaquinoxaline. The authors conclude that further work is needed on the timing of treatment and on the relative efficacy of Sulfamerazine, Sulfamethazine and other drugs. J.T.E.

A study of subclinical worm infestation in sheep. 1. The effect of level of infestation on the growth of the lamb. C. R. W. Spedding and T. H. Brown, *J. agric. Sci.*, 1957, **48**, 286–93.

Ten pairs of male and 10 pairs of female lambs born in March 1955 were transferred with their ewes within 24 hours of birth to a ley that had carried no ruminants for 2 years. The animals were moved into a fresh paddock every day and never returned to an area once grazed. When the lambs were about 6 weeks old half were infected by drenching with a suspension of 34, 68, 102, 136 or 170 nematode larvae in water daily for 5 weeks; each level was composed of one pair of male and one pair of female twins; twins were not split between the treatments because of the greater risk of cross infection, but all the lambs grazed together after May 23rd (end of the drenching period). Every fortnight the lambs were weighed, the length of the right hind cannon bone, the width of hooks and the length of pelvis were measured and egg counts taken. No eggs other than those of

Strongyloides papillosus (less than 0·3 e.p.g.) and an occasional egg of *Trichuris ovis* were found in the control lambs; in the infected lambs counts averaged 13, 22, 27, 37, and 51 e.p.g. Live weight gains showed a quadratic trend. The difference in live weight gain between the control group and the infected groups as a whole was 5·5 lb. per head between April 18th (date of first infective dose) and July 12th. Skeletal measurements of the most heavily infected group were less than those of the controls, but no consistent trend was found in the less heavily infected groups. S.F.A.

The efficiency of phenothiazine against *Trichostrongylus colubriformis* in sheep. L. K. Whitten, *N.Z. Vet. J.*, 1956, **4,** 63–8.

The author quotes from the literature to show the divergent results obtained by different workers with phenothiazine against species of *Trichostrogylus* in sheep. He himself carried out many experiments extending over four seasons in New Zealand and involving over 600 weaned lambs, all of which were slaughtered to obtain evidence of worm burden after treatment or after use as untreated controls. The infecting dose of *T. colubriformis* larvae was either 40,000 or 60,000. The single dose of 7–10 g. phenothiazine was given either 10 or 20 days after infection. The material varied in country of origin, maker, particle size and physical form (powder or tablet). Administration was either by stomach tube into the rumen or through an oesophageal tube into the abomasum. The efficiency of phenothiazine varied tremendously in the different experiments, from 0 to 88%. Fine particle phenothiazine was much more effective than coarse samples, with efficiencies of 52–82%. Efficiency was not enhanced by placing the drug in the abomasum. J.T.E.

Studies on anthelmintics for sheep; dihydroxyanthraquinones and some other quinones. H.McL. Gordon, *Aust. Vet. J.*, 1957, **33,** 39–42.

The author investigated the anthelmintic activity of 1:8-dihydroxyanthraquinone in sheep. Preliminary tests indicated that the recommended dose of 5 g. of Diaquinone as a purgative for sheep was rather excessive, and lower doses were tried. Doses of 2·5–4 g. injected into the rumen caused mild purgation in most sheep. Laboratory trials showed that in the above dosage there was an inconstant effect upon *Haemonchus contortus* and a lesser effect upon species of *Trichostrongylus* and *Ostertagia*. The effect of a dose of 1–2 g. against *Trichostrongylus colubriformis* was slight when injected in the abomasum and nil when injected into the rumen. The drug was, however, effective against parasites of the large intestine. A dose of 2·5–5 g. was 100% effective against *Oesophagostomum columbianum;* 1–2 g. was variably effective against *Trichuris* spp.; 1 g. was 75–100% effective against *Chabertia ovina*, and 1 g. was 100% effective in 4 out of 5 sheep infested with *Oe. venulosum*. In field trials in Western Australia three groups of twenty 4-month-old lambs were given monthly doses for 10 months of either Cunic or Diaquone, the latter in dosage of 1 g. up to 8 months of age and 2 g. afterwards. The effect of this treatment against *Chabertia ovina* was estimated by egg counts: Diaquone was found to be highly effective and Cunic ineffective. In New South Wales the action of Diaquone against *Oe. columbianum* was tested in two groups of ten sheep in dosage of 1 g. and 2 g. respectively, the drug being administered after being shaken up with 1 g. of copper sulphate in water. The drug in the lower dosage removed all the worm from 6 sheep, and in the higher dosage from 9 sheep. A mixture of 1·5 g. of Diaquone with 5 g. of phenothiazine was not effective. In the sheep in which Diaquone caused severe purgation the liver was found to show diffuse cloudy swelling and the kidneys a similar change; but the lambs in the experiment in Western Australia were not harmed by the drug. Three other dihydroxyanthraquinones were found to be inferior to Diaquone, as also were several chemically related compounds. The most useful contribution to anthelmintic therapy made by Diaquone is its effect upon nematodes of the large intestine, particularly *Trichuris* species, which is resistant to all the established anthelmintics. It joins phenothiazine in being highly effective against *Oesophagostomum* and fully effective when administered into the rumen. There is a need to investigate the hepatic and renal toxicity of Diaquone before it can be safely released. J.T.E.

Distomatose-bestrijding door middel van capsules tetra-chloorkoolstof. (Control of distomatosis by means of carbon tetrachloride capsules.) Y. Heida, *Tijdsch. Diergeneesk*, 1956, **81,** 1019–24.

After failing to control liver fluke disease with the aid of agricultural salt spread on the ground (in the hope of eradicating the snail vectors) the author investigated the value of monthly doses of carbon tetrachloride. On each of four farms 3-month-old lambs were divided into 3–4 test and 2–3 control animals. On two farms each test lamb received 1 cc. of carbon tetrachloride in capsule per month for 4 months and on the other farms 2 cc. per month for 3½ months, between July and January. When the sheep were examined after slaughter in January, liver fluke counts at the four centres were, for test and control animals respectively: 8·7, 13·3; 17, 277; 6·4, 25·3; 10, 56·3. The treated sheep showed corresponding gains in live weight over the controls of 2·2, 5·7, 0·7 and 2 kg. The author considers that these results justify the control of liver fluke disease by the monthly administration of carbon tetrachloride and that, under suitable management, liver flukes might be eradicated from farmland through the elimination of adult flukes from sheep. J.T.E.

The toxic effect of certain seed-dressings on wild and game birds. R. B. A. Carnaghan and J. D. Blaxland, *Vet. Rec.*, 1957, **69,** 324–5.

From feeding trials conducted at the Ministry of Agriculture's Veterinary Laboratory, Weybridge, it has been established that grain dressed with dieldrin is toxic to pheasants and woodpigeons, and this is believed to explain the severe mortality encountered among these birds in certain areas of southern England in 1956. The administration of washings from as little as 1½ oz. of dressed seed proved lethal to pigeons. Death occurred 4–10 days after taking the grain. Grain dressed with organomercurials and γ–BHC was not toxic. D.L.

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